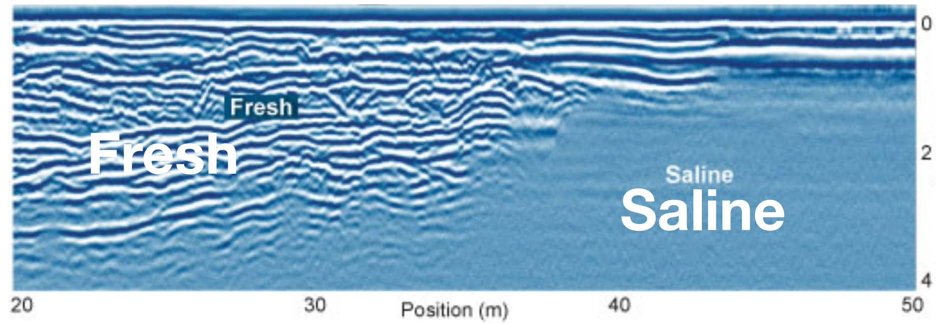
Ground Penetrating Radar

DISC
2017
Electromagnetics
Fundamentals and Applications

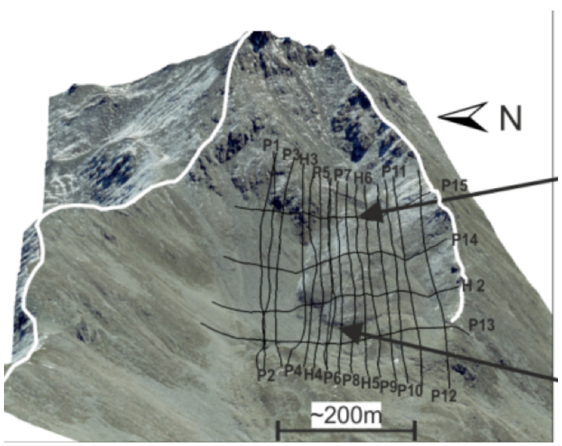
Motivation

Sink holes

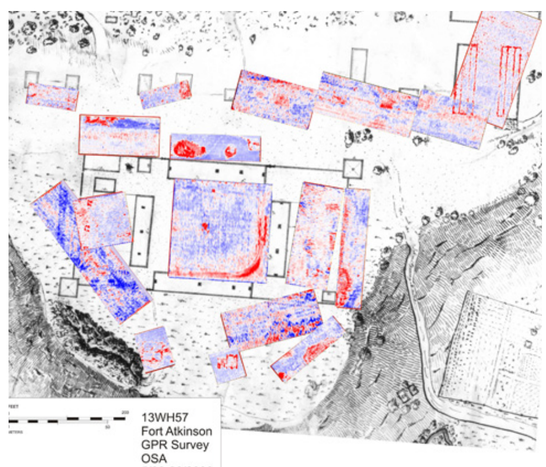
Salt Water Intrusions



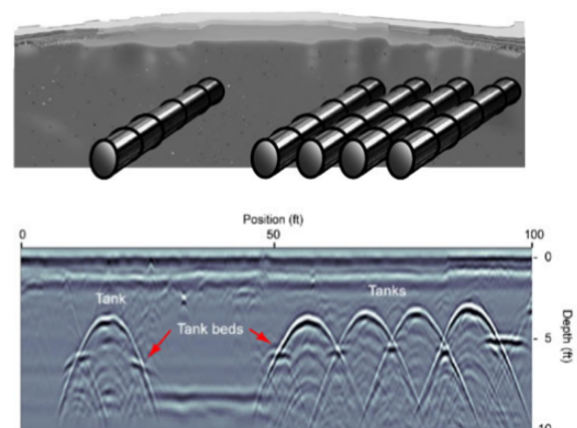
Rock glacier



Archeology



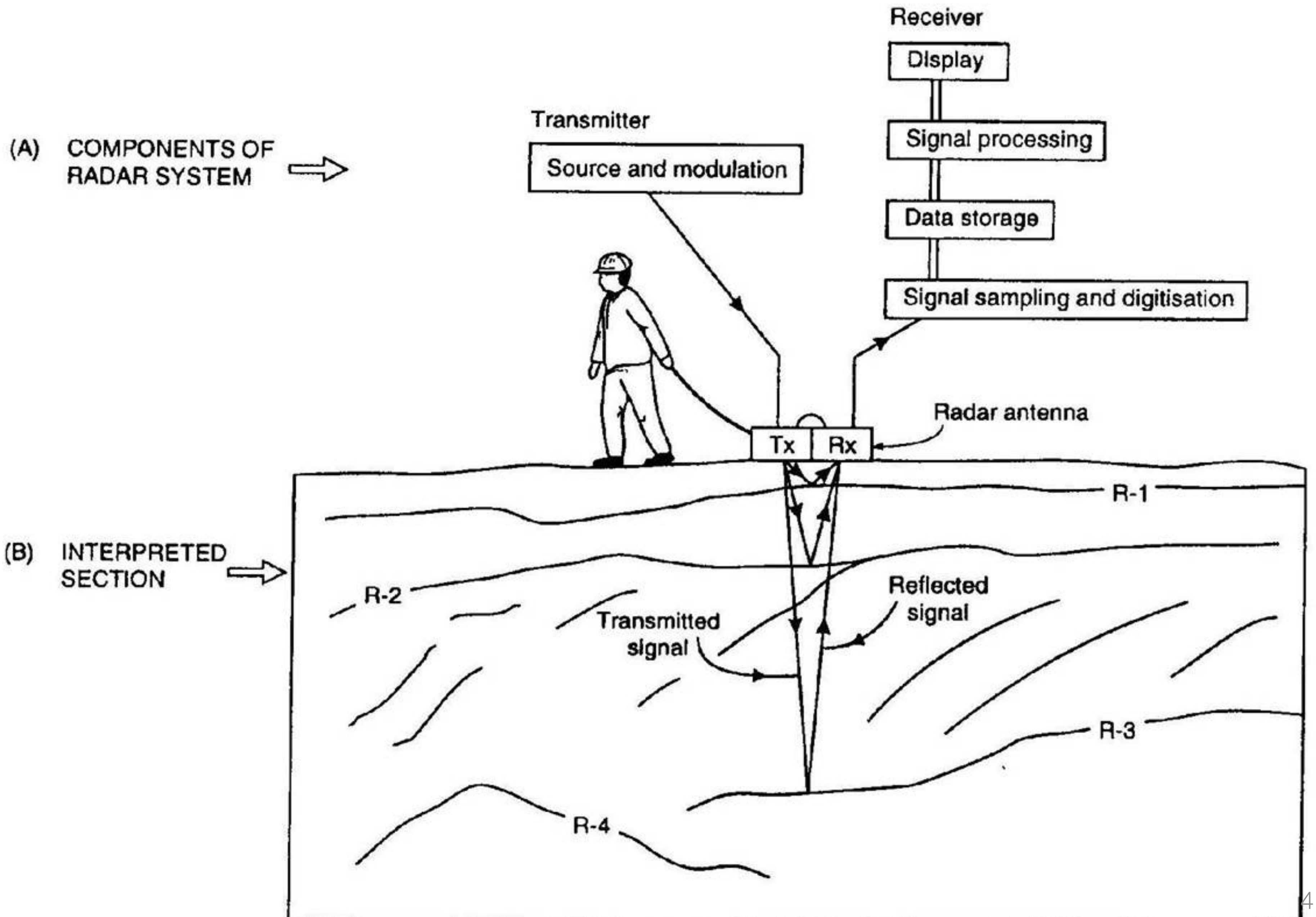
Underground tank



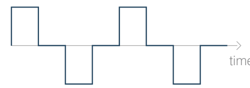
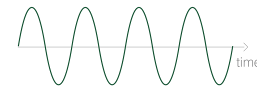
Outline

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

Basic Experiment



Basic Equations

	Time	Frequency
	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

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

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

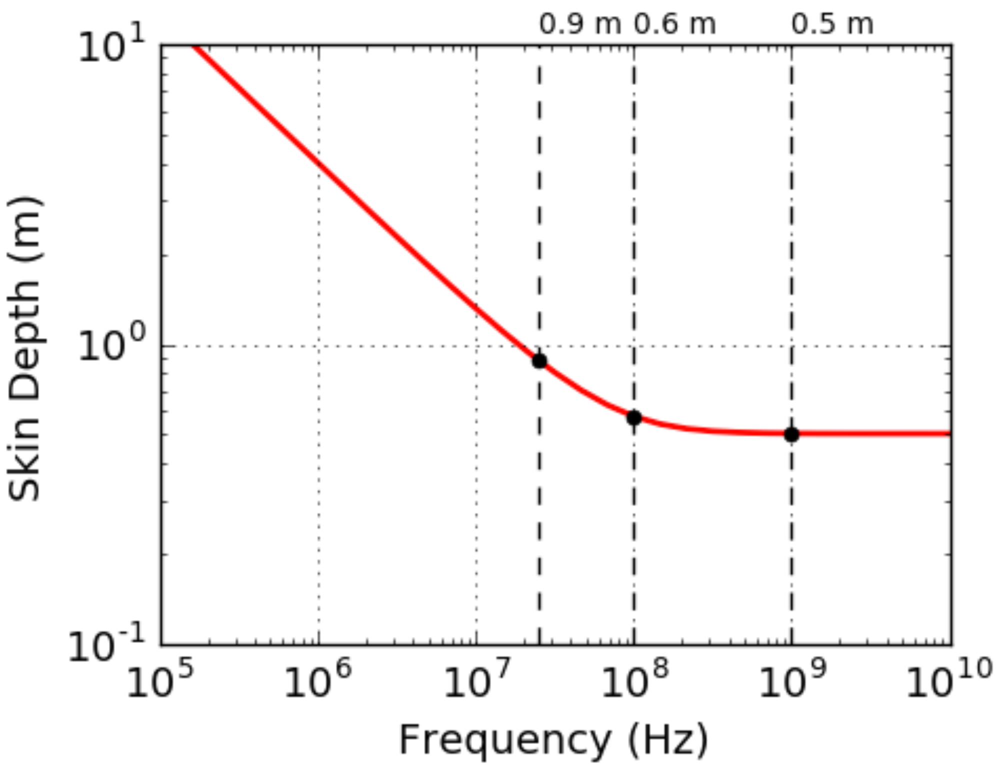
* Same equation holds for E

Physical properties

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

Material	Relative Permittivity	Conductivity (mS/m)	Average Velocity (m/ns)
Air	1	0	3
Fresh Water	80	0.5	0.033
Sea Water	80	3000	0.01
Ice	3-4	0.01	0.16
Dry Sand	3-5	0.01	0.15
Saturated Sand	20-30	0.1-1	0.06
Limestone	4-8	0.5-2	0.12
Shales	5-15	1-100	0.09
Silts	5-30	1-100	0.07
Clays	5-40	2-1000	0.06
Granite	4-6	0.01-1	0.13
Anhydrites	3-4	0.01-1	0.13

Attenuation: Skin Depth

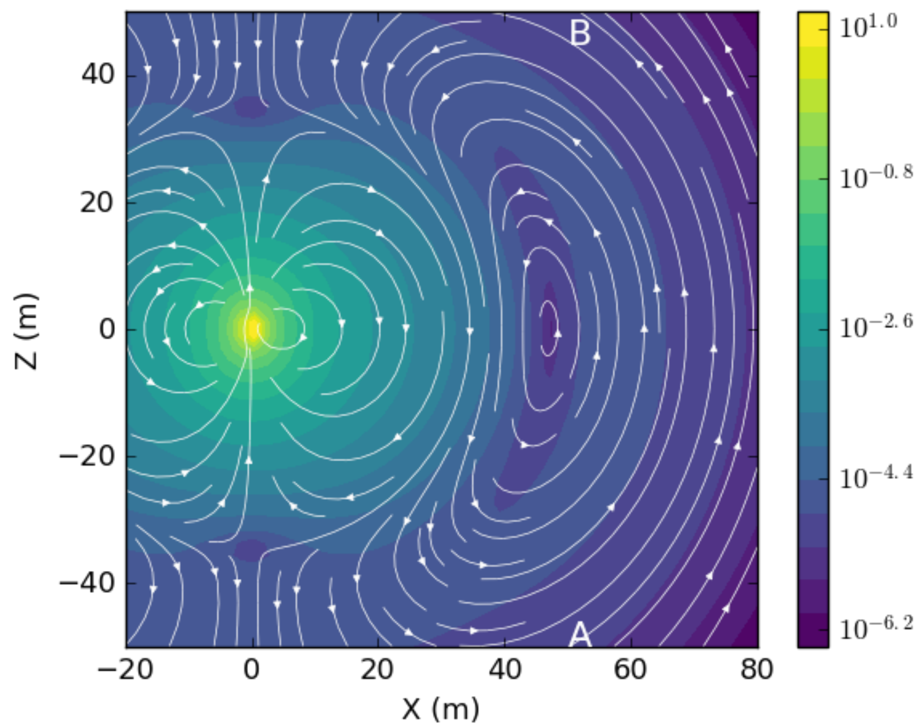


δ : skin depth

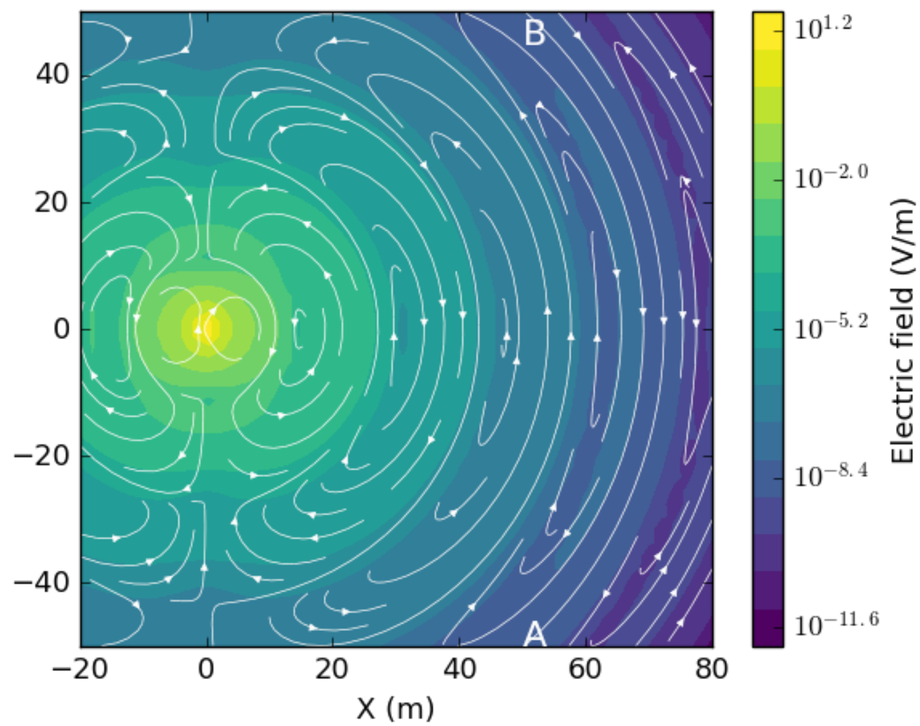
$$\delta \approx \begin{cases} 503\sqrt{\dfrac{1}{\sigma f}} & \text{for } \omega\varepsilon \ll \sigma \\ 0.0053\dfrac{\sqrt{\varepsilon_r}}{\sigma} & \text{for } \sigma \ll \omega\varepsilon \end{cases}$$

Electric Dipole in a Whole Space

10^5 Hz



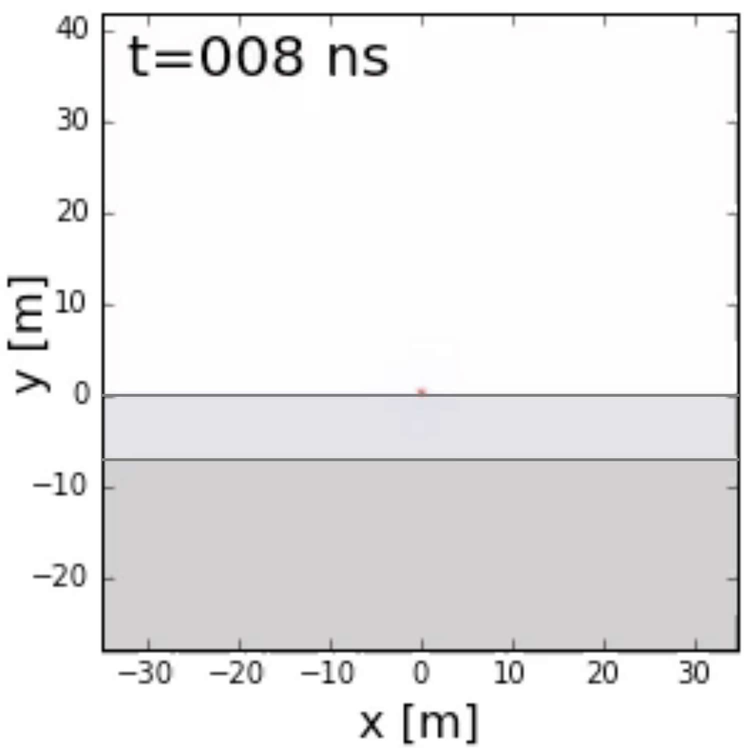
10^6 Hz

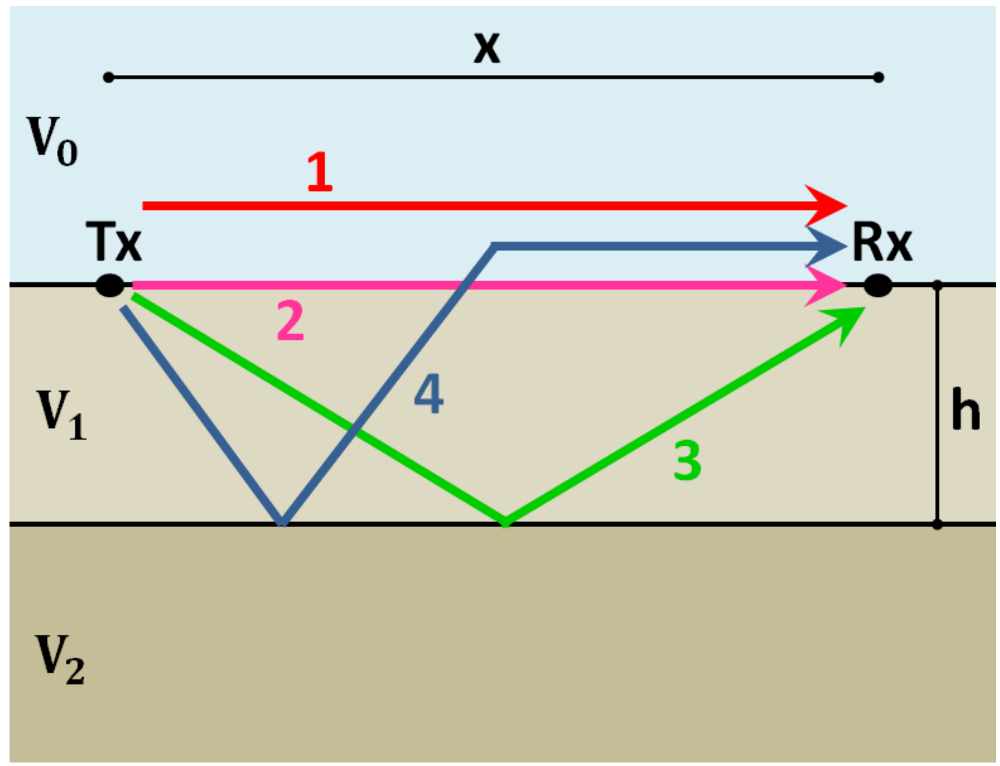


$$\lambda = \frac{v}{f}$$

Waves and Rays

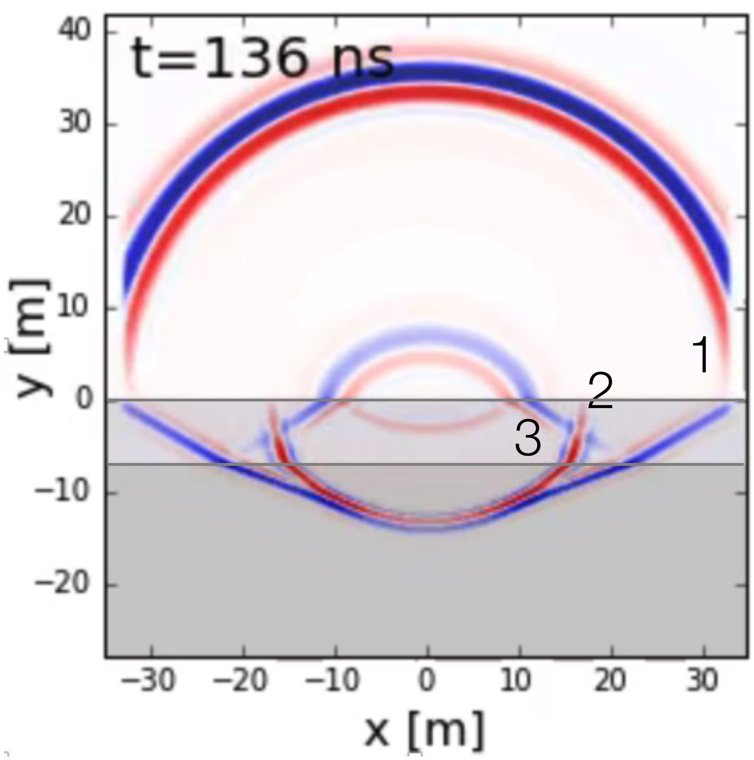
$$v = \frac{c}{\sqrt{\varepsilon}}$$

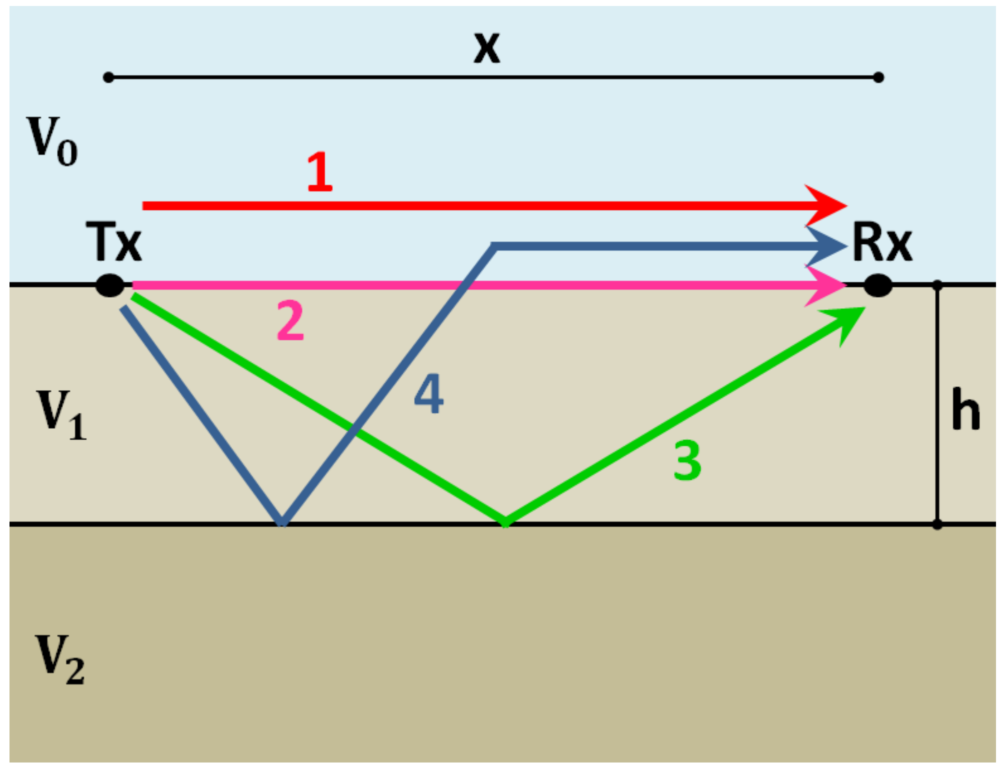




Waves and Rays

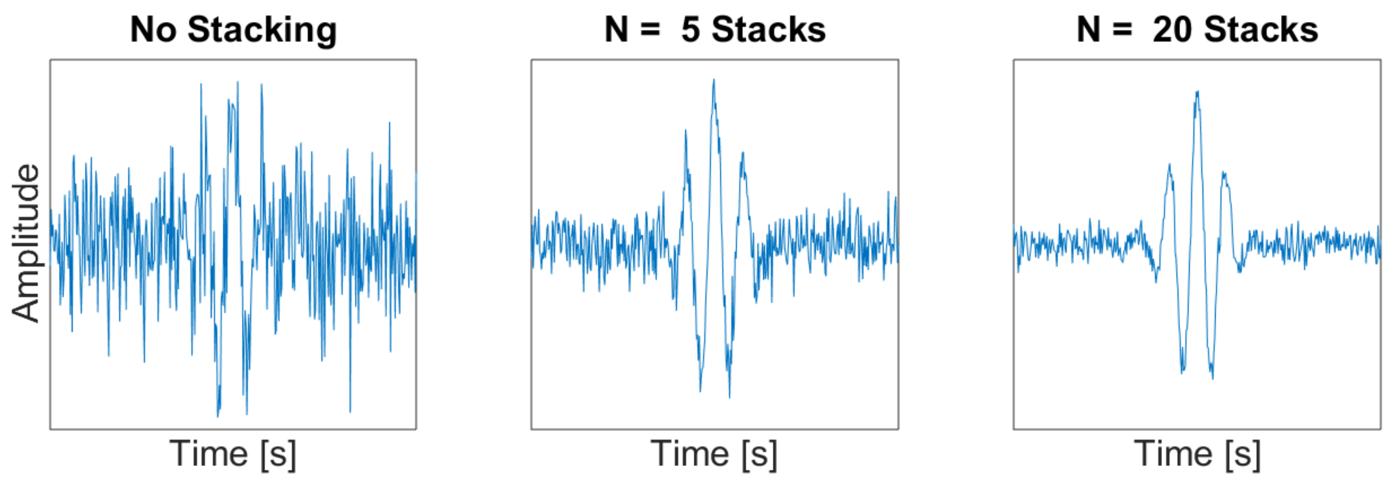
$$v = \frac{c}{\sqrt{\varepsilon}}$$



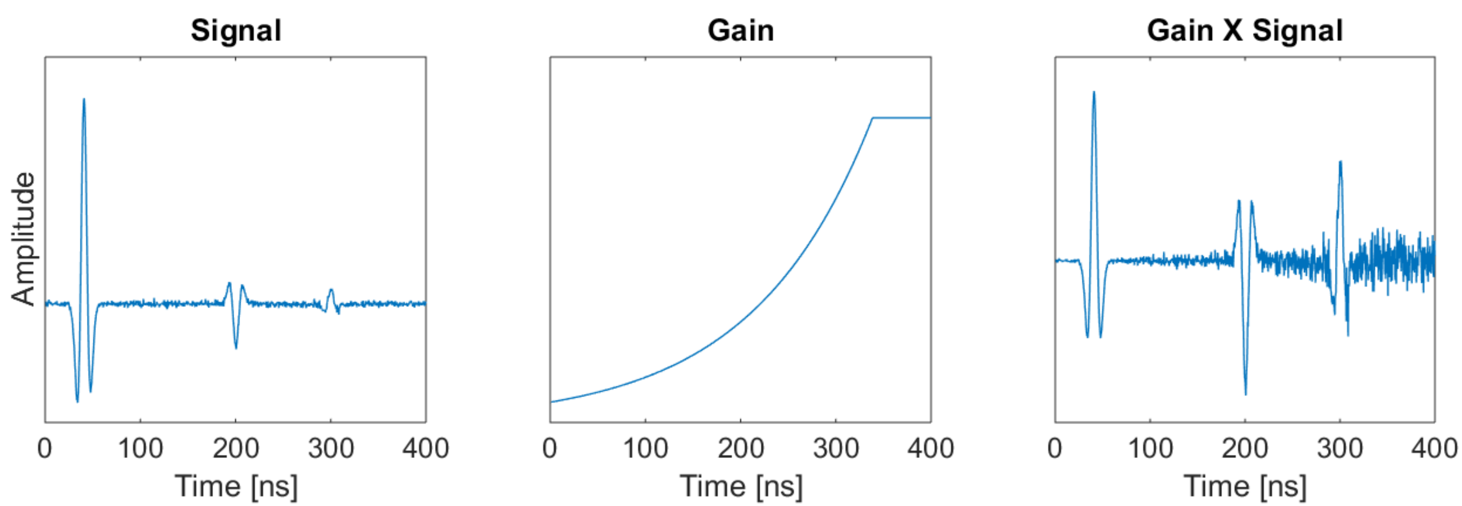


Processing

Stacking

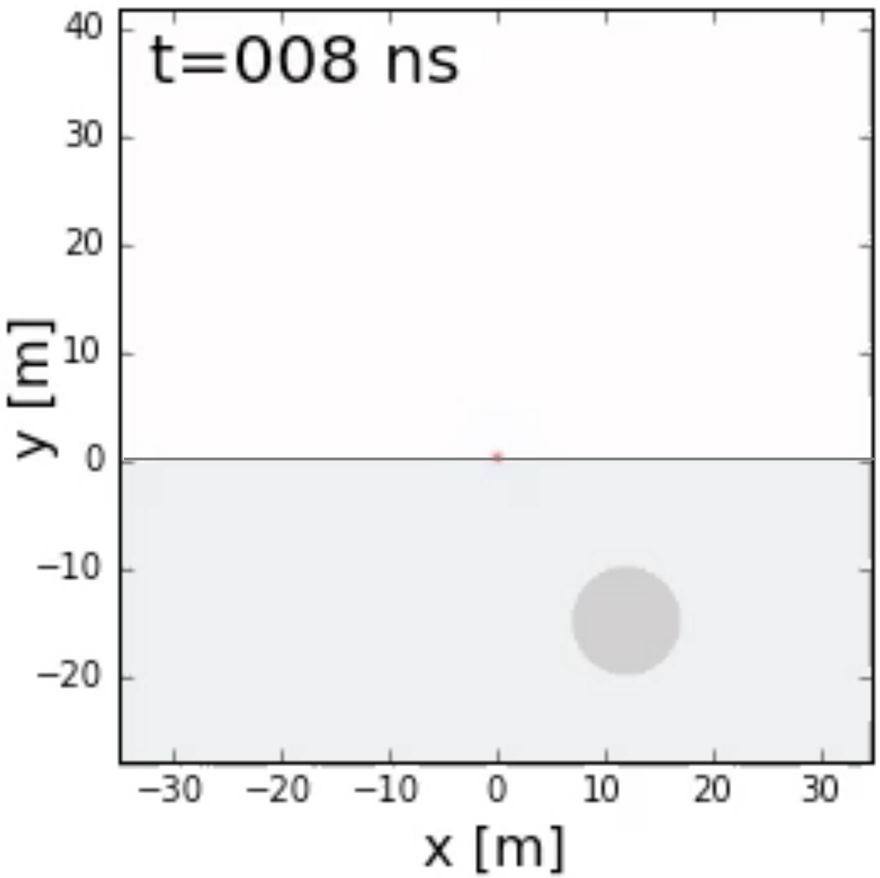


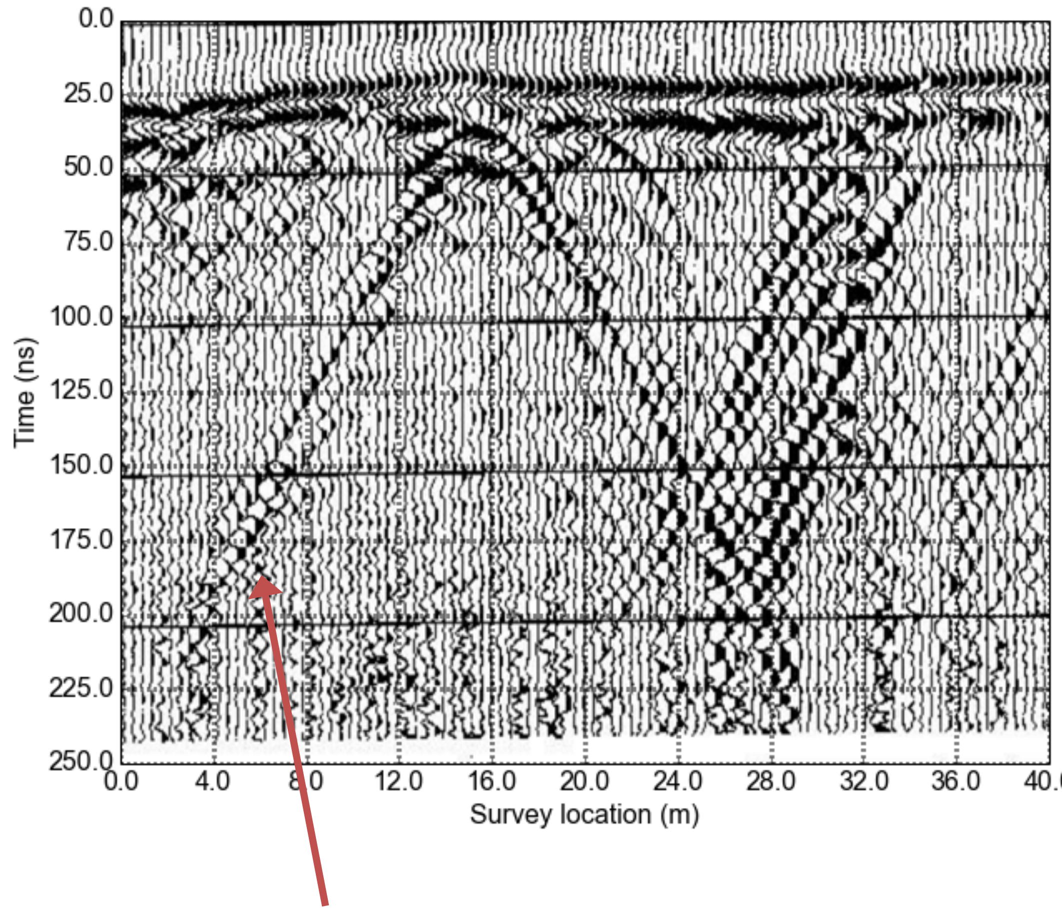
Gain Control



Radargrams

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





Hyperbola

slope ~ 2/v

Outline

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

- Questions?

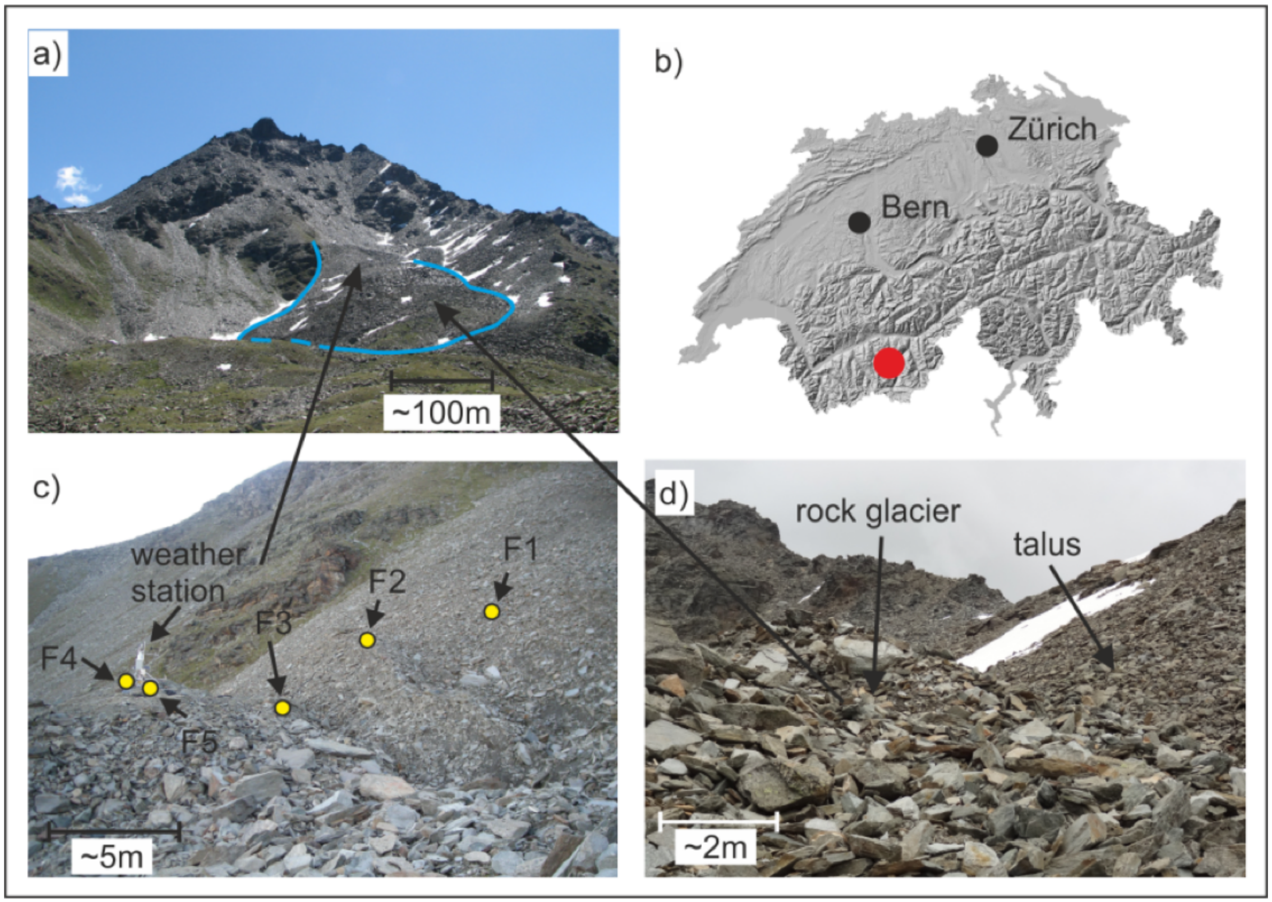
- Case history: rock glacier

Case History: Furggwanghorn

Merz et al, 2015

Setup

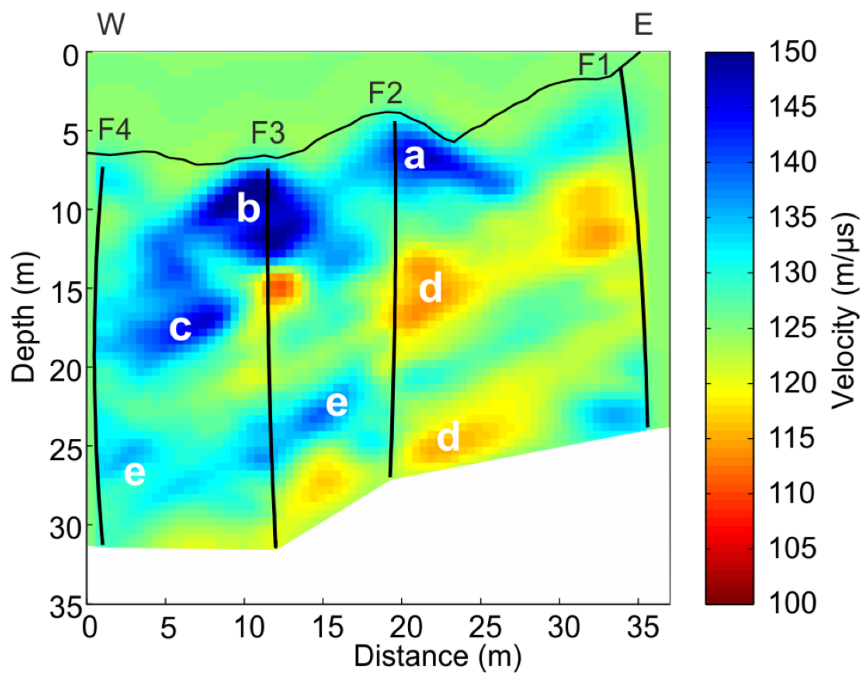
- Downslope movement shown to increase from 1.5 m/yr to 4.0 m/yr.
- Aim: characterize rock units and evolution of glacier
- Surface GPR: unsuccessful (too close to scatterers)
- Helicopter GPR used



Properties

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

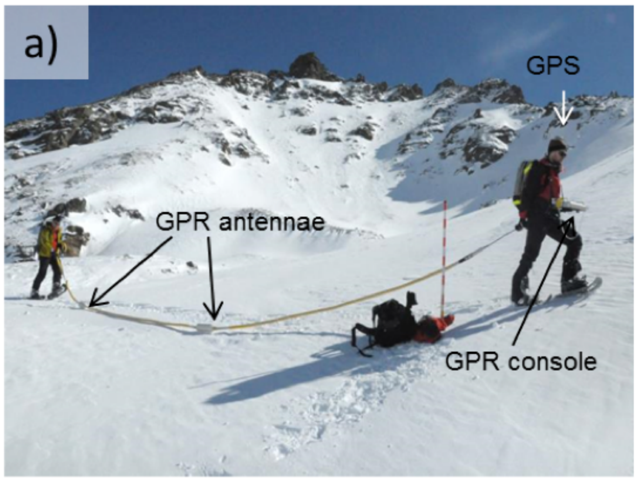
Velocity from cross well GPR



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

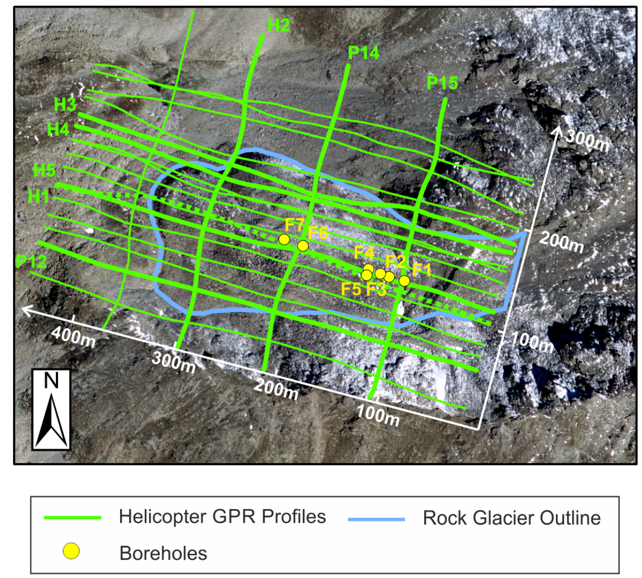
Survey

Ground-GPR



Heli-GPR

Survey lines



- 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

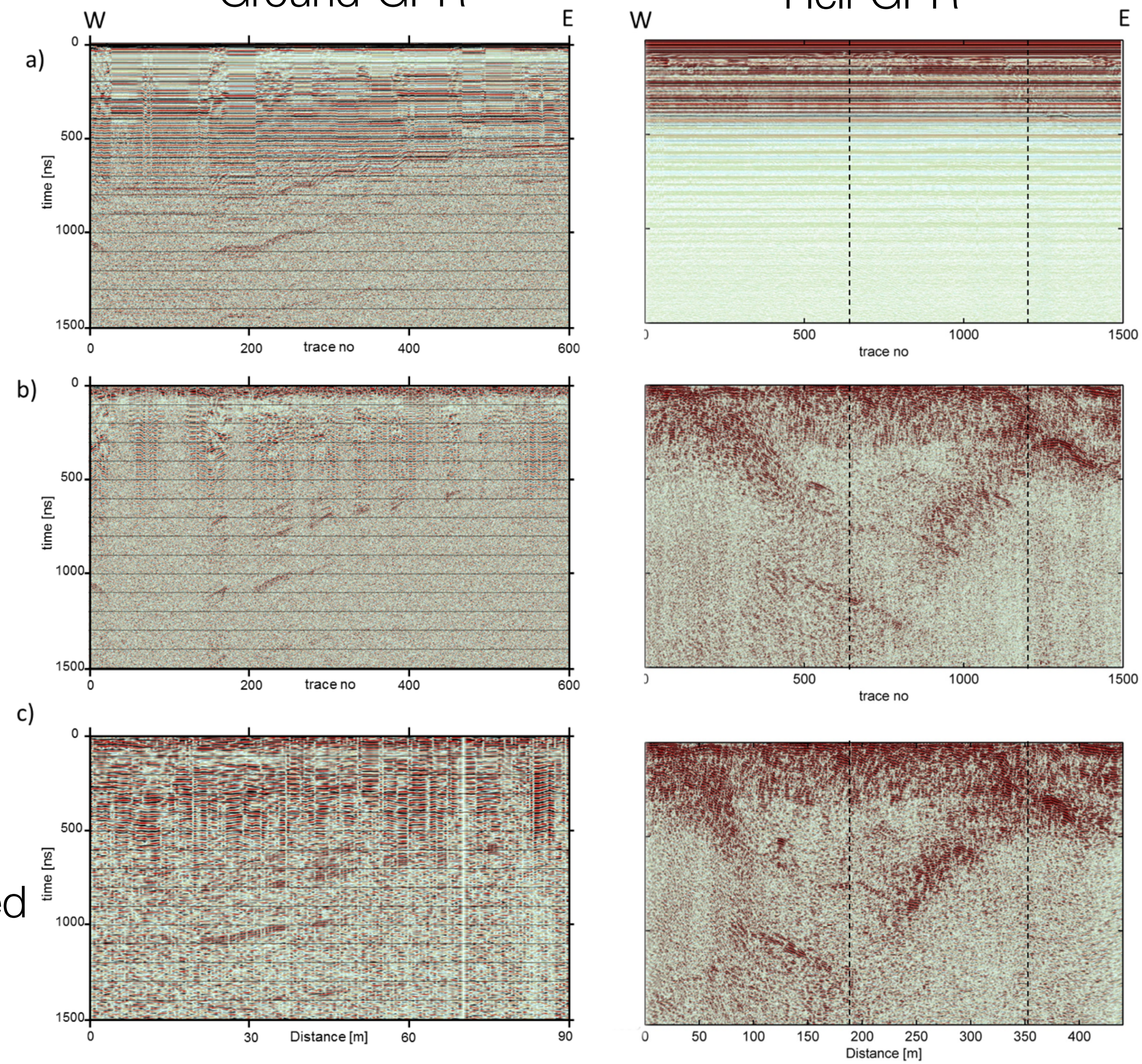
Data and Processing

Ground-GPR | Heli-GPR

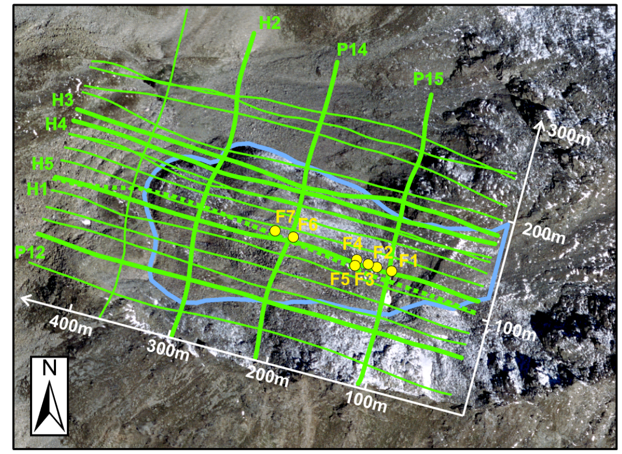
Raw

Filtered

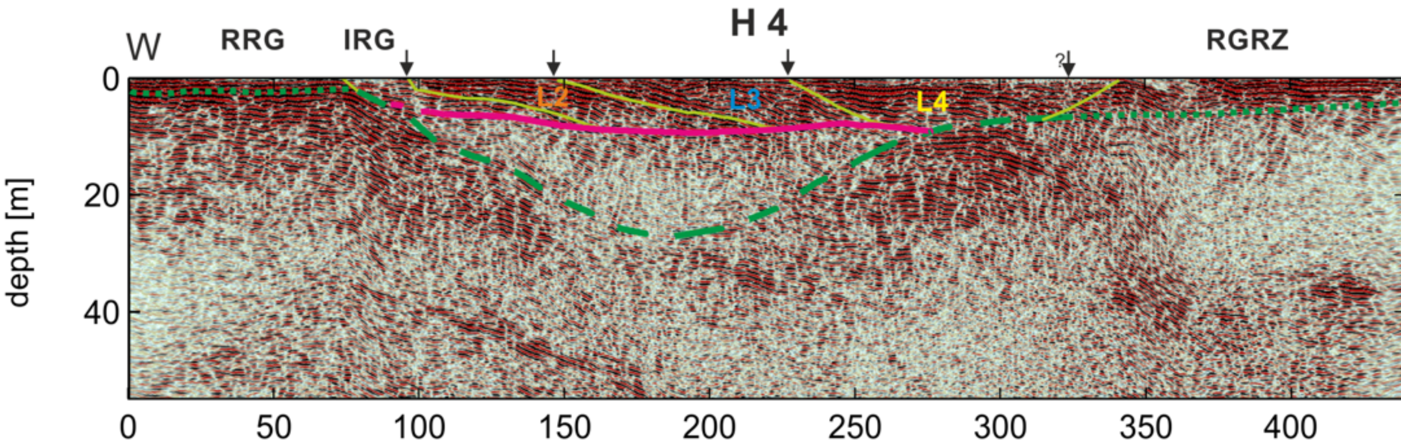
Final Processed



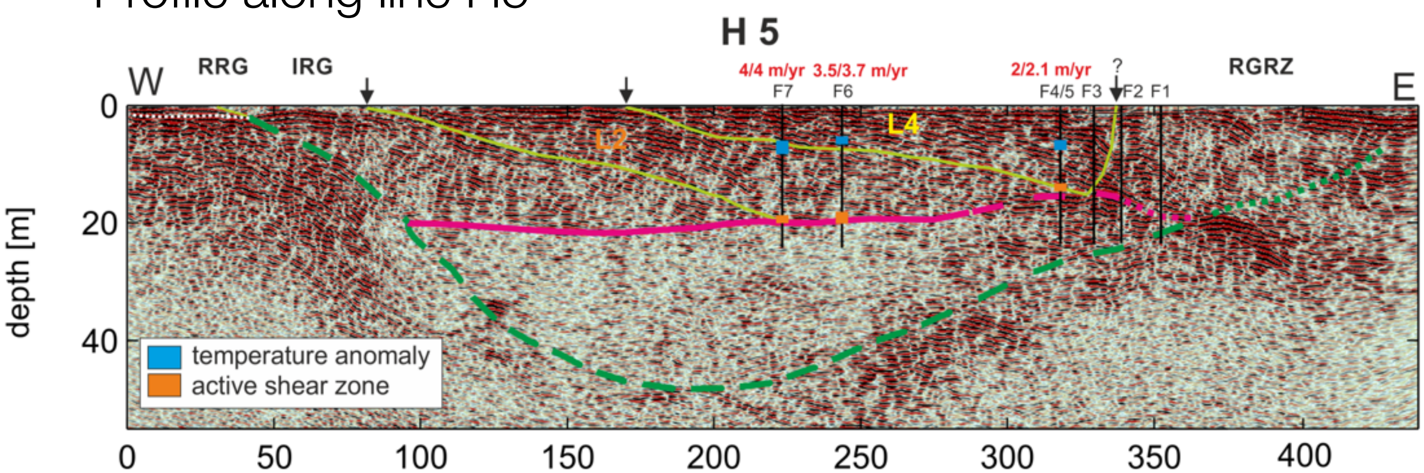
Interpretation



Profile along line H4



Profile along line H5



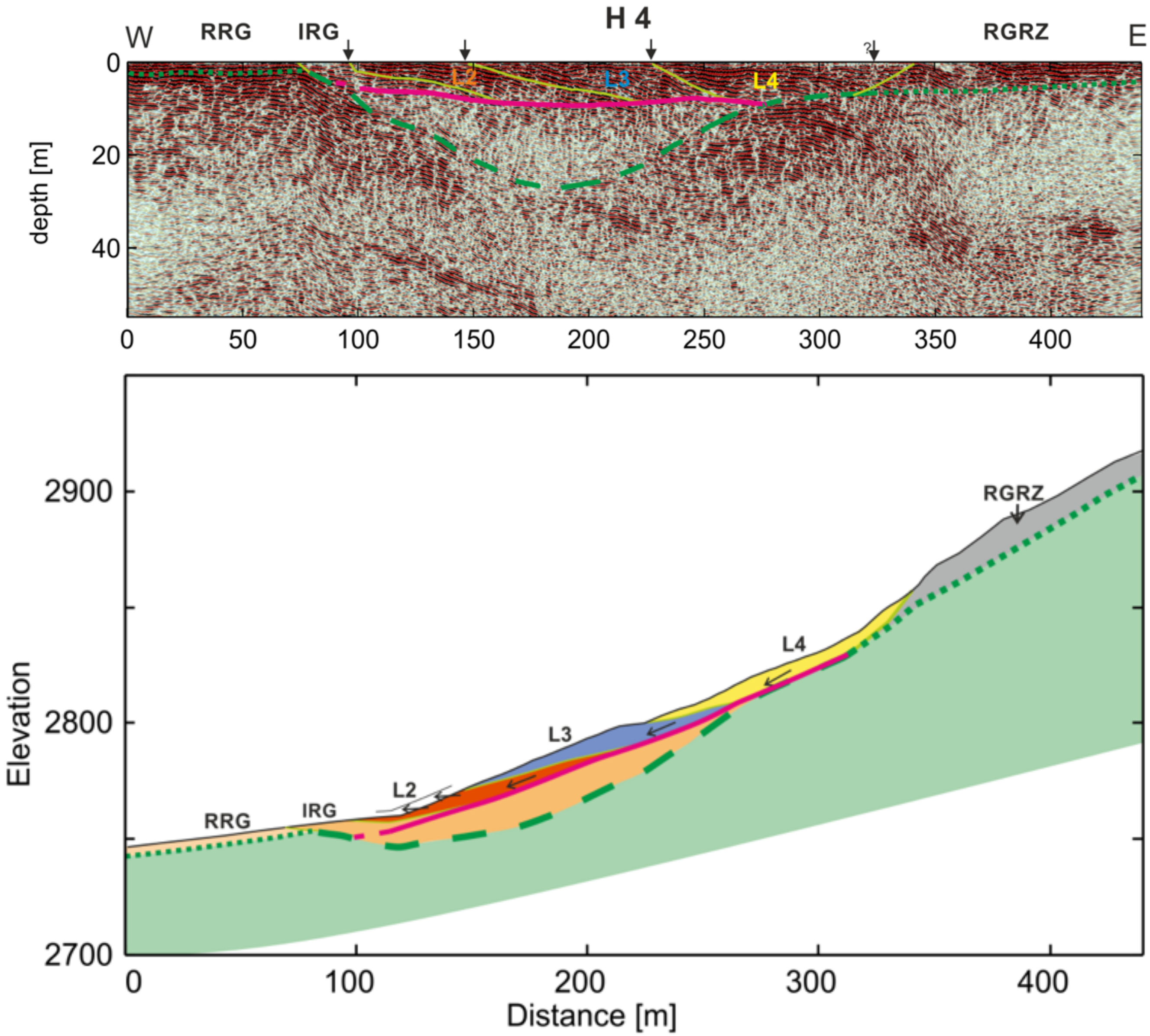
- - Bedrock surface

— 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

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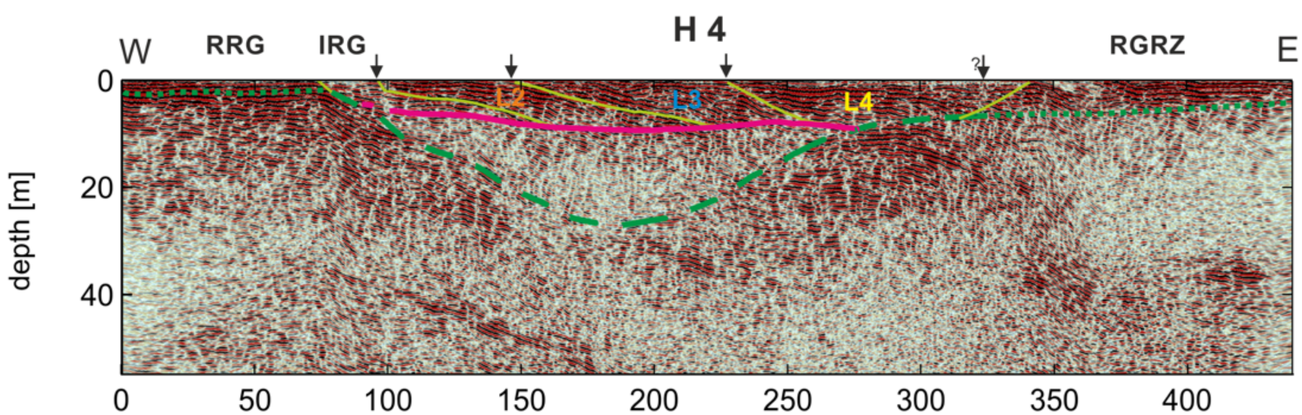
- Case history: rock glacier



End of GPR

- Introduction to EM
- DCR
- EM Fundamentals
- Inductive sources
  - Lunch: Play with apps
- Grounded sources
- Natural sources
- GPR
- Induced polarization

Next up

- The Future