Evaluation of Ice-Coupled and Elevated GPR Antenna Acquisition on Ice

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Abstract

We compared two acquisition methods for near surface ground penetrating radar (GPR) in ice-over-fresh-water-over-ground environments. In the first method, the antennae were coupled directly to the ice as in conventional acquisition (**Fig. 1a**). In the second approach, the antennae were elevated 0.5 m above the ice surface (**Fig. 1b**). Numerical comparison of reflectivity suggests that no significant degradation of signal results from elevation of the antennae. We verified the numerical result with real-data acquired at Ghost Lake, Alberta. Data acquired over the same linear traverse was compared, only a slight degradation of the target signal was apparent.

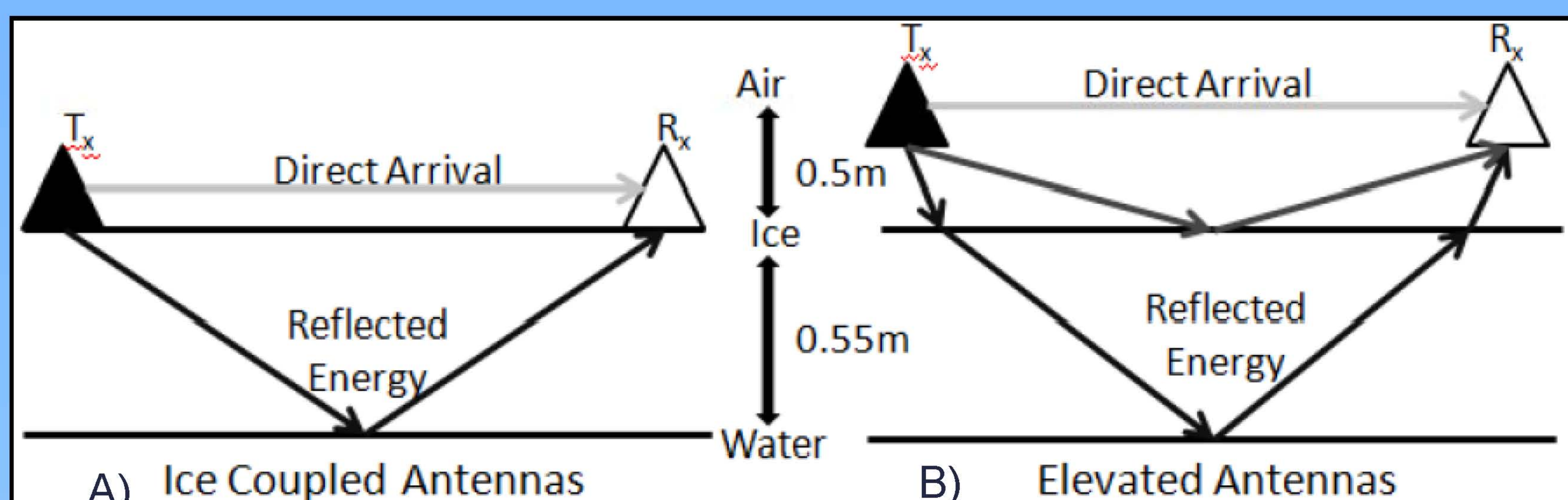


Figure 1: A) Near surface ray paths for the two acquisition methods. Antennas are coupled with the Ice. **B)** Antennas are elevated. T_x represents Transmitter, R_x represents Receiver.

Objectives

1. Challenge traditional/surface-coupled GPR acquisition with the goal of advancing the development of an efficient elevated antennae system.
2. Numerically determine the impulse response for coupled and elevated antennae experiments.
3. Evaluate transmission losses caused by the addition of the air-ice interface when the antennae are elevated.
4. Qualitatively compare two datasets acquired at Ghost Lake, Alberta that used both acquisition methods.

Theory

- Ground penetrating radar uses two antennas in transmitter/receiver pair to emit an electro-magnetic (EM) wave into the subsurface and detect its reflections back to the surface **(Fig. 2)** .
- Three electrical properties control EM wave propagation:
  - Dielectric permittivity (ε). Note: ε_0 represents permittivity of free space
  - Electrical conductivity (σ).
  - Magnetic permeability (μ).
- EM reflections are caused at interfaces that contain a contrast in dielectric permittivity.
- Snell's Law of refraction **(Eqn. 1)** determines ray path geometry **(Fig. 3)**.

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 = p \qquad n_j \sim \sqrt{\frac{\varepsilon_j}{\varepsilon_0}}$$

Eqns. 1 and 2

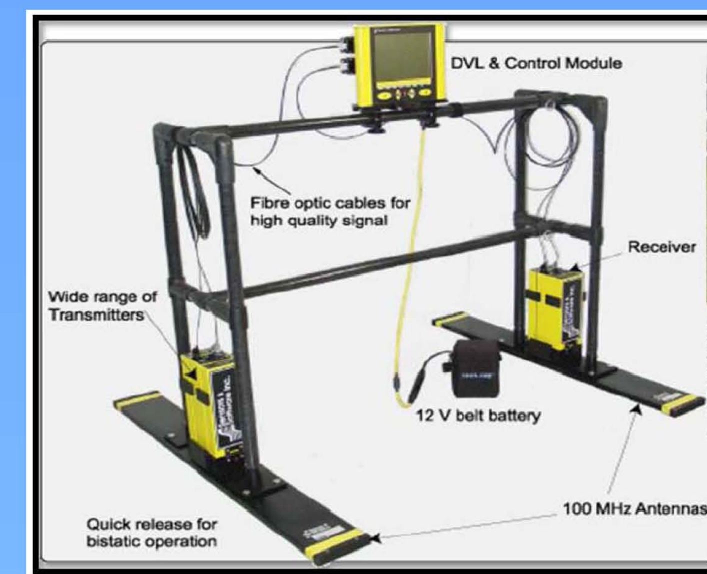
- Fresnel equations define the relative magnitudes of transmitted and reflected rays **(Eqns. 3 and 4)**.

$$R = \frac{n_1 \cos\theta_1 - n_2 \cos\theta_2}{n_1 \cos\theta_1 + n_2 \cos\theta_2}$$

Eqn. 3

$$T = \frac{2\, n_1 \cos\theta_1}{n_1 \cos\theta_1 + n_2 \cos\theta_2}$$

Eqn. 4



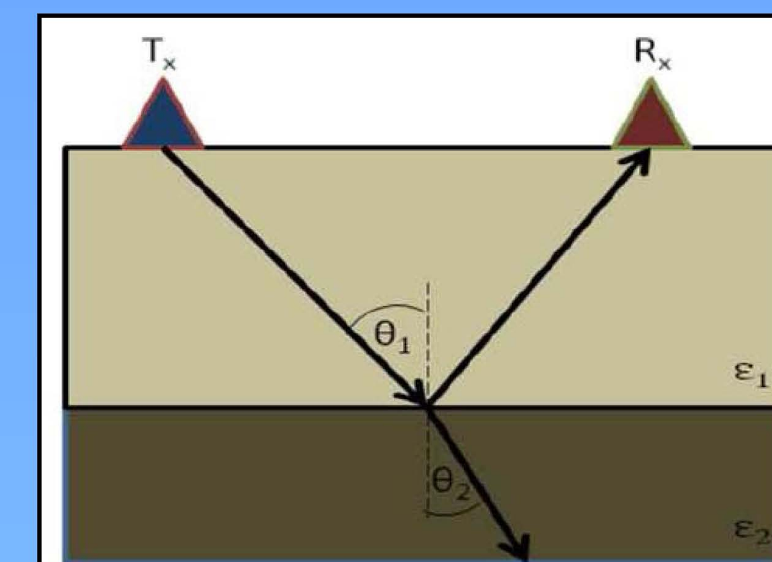
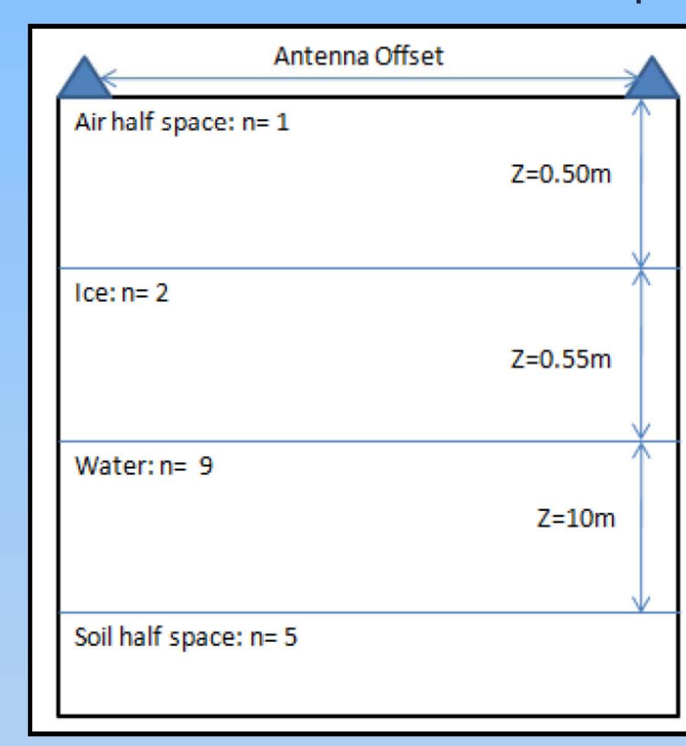


Figure 2: PulseEkko Pro system with labelled components. **Figure 3:** Basic GPR ray paths that show reflected and transmitted wave.

Numerical Modeling

Using a 4 layered model **(Fig. 4)**, the impulse response is calculated for each reflecting interface **(Fig. 5)**. Impulse response represents the relative amplitude of the received signal and is used to measure signal degradation between elevated and ice-coupled experiments.



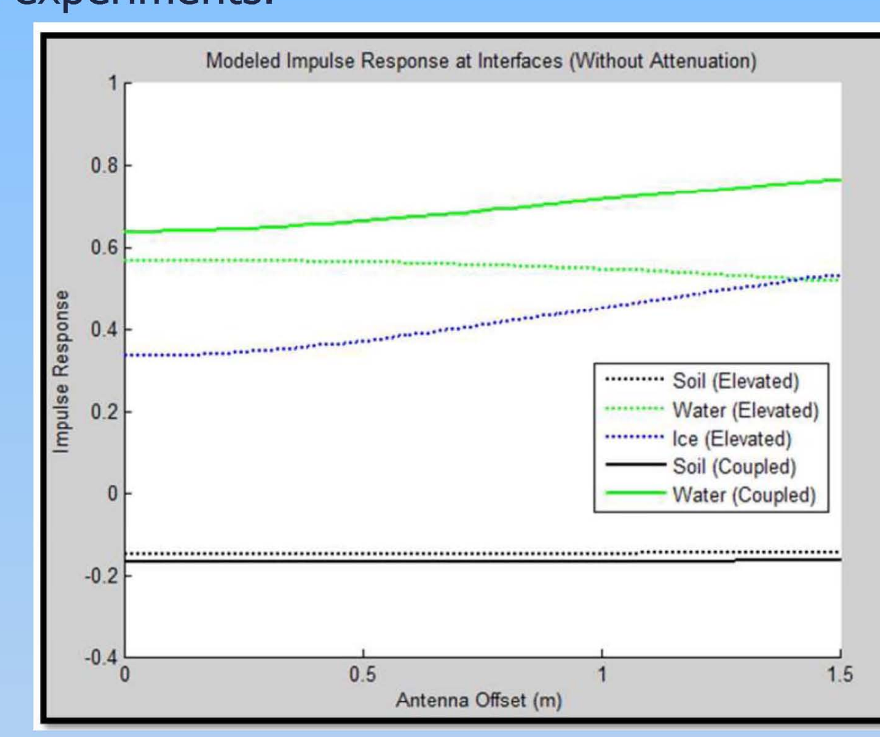


Figure 4: Cross-section of layers used in the impulse response model. Z is the layer thickness and n is the refractive index. **Figure 5:** Modeled impulse response from known interfaces

Field Site/Experiment Parameters

- Data was acquired form Ghost Lake, Alberta located 45 km west of Calgary along highway 1A. The yellow line in **figure 6** shows location of dataset.
- Rocks wrapped in tinfoil are frozen 55cm into the ice and situated at 20m intervals along the line. They are used to calibrate the migration and act as reference points.

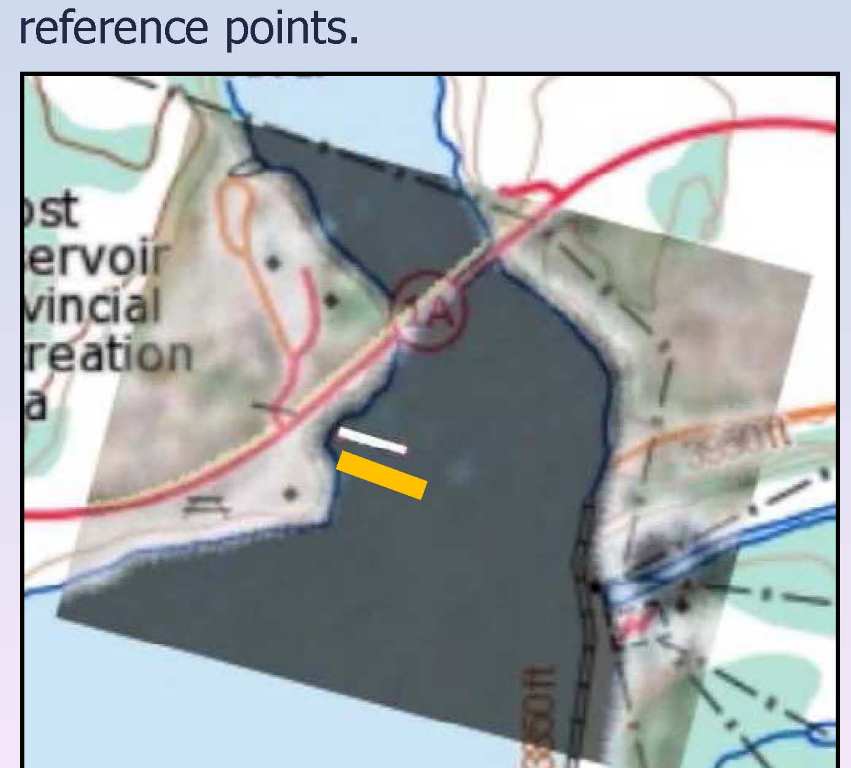


Figure 6: Map showing location of GPR dataset.

Time Window	300 ns
Step Size	0.1 m
Nominal Frequency	200 MHz
Antenna Separation	1 m
Stacks Per Trace	64
Sample Rate	0.4ns

Table 1: Survey Properties.

Ghost Lake Data

Processing

Datasets were processed using Sensor and Software's, Win Ekko Pro program. While the software allowed easy manipulation of the data, there were several limitations to its capabilities. Most notably, the migration package only allowed a single velocity to be entered into the algorithm. Due to the extreme velocity contrast between Ice and water, the migration failed to collapse the diffractions.

Figure 7: Workflow for processing GPR data.

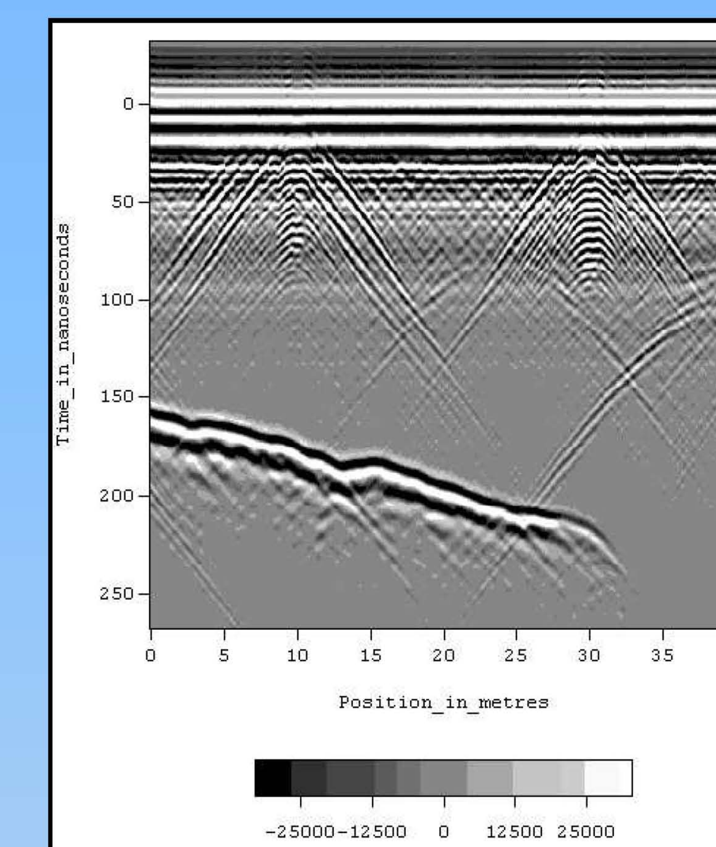


Figure 8: Un-migrated dataset with ice-coupled antennae

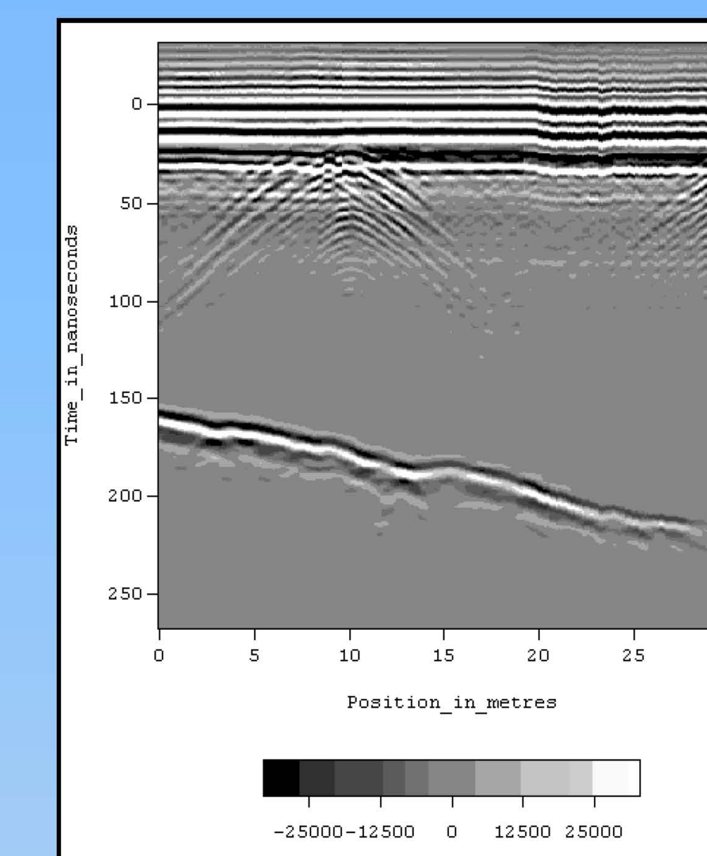


Figure 9: Un-migrated dataset with elevated antennae

Analysis

- A qualitative test of modeled results is a comparison of traces shot at the same location, using the both antenna coupling systems.
- The impulse response model predicted a slight amplitude reduction for all events when antennae are elevated.
- This result is consistently seen in Ghost Lake data **(Fig. 10)**.

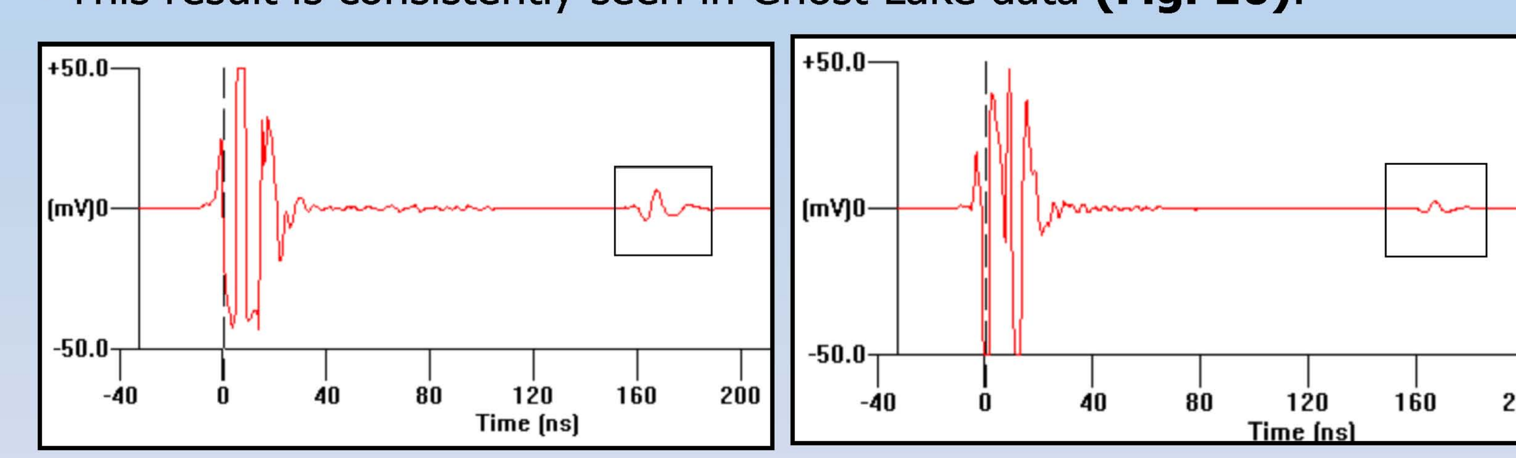


Figure 10: A) Ice coupled trace at 2.7 m. **B)** Elevated Antennae trace at 2.7m. The black box represents the reflection caused by the lake bottom.

Conclusions

- When the antennas are raised, a portion of the transmitted energy is reflected off the air-ice boundary which reduces the absolute amplitude received from deeper reflections.
- Since ice and air have a similar dielectric permittivity, the difference between the two methods is small due to the transparent nature of air-ice interfaces to GPR analysis.
- The most pronounced difference in amplitude for the two acquisition methods occurs at the ice-water boundary while a smaller contrast is seen at the lake bottom.