TBL # 4: Glacier Applications for Ground Penetrating Radar (GPR)

DUE: Monday October 23th, 2017

Overview

Ground penetrating radar (GPR) sends a pulse of electromagnetic waves into the Earth. As GPR signals propagate through the Earth, they reflect, transmit and refract at interfaces. The propagation of the GPR signal depends on the frequencies contained in the source wavelet and the electromagnetic properties of the Earth. Because GPR uses high frequencies, it provides high resolution images of subsurface structures.

This exercise is split into two parts: (1) propagation of GPR wavefronts and (2) exploring the use of GPR in glacial environments. Questions in part 1 will be answered with the help of a GPR Movie . For part 2, you are expected to read the Glacier Girl case history. Glacial environments represent a unique and important application of ground-penetrating radar. Questions in part 2 will follow the 7 step framework.

Instructions

Read the Glacier Girl case history and answer all multiple choice questions in the assignment. The assignment should be completed **before** class on the specified due date.

Resources

- GPG Geophysical Surveys: Ground Penetrating Radar
- GPR Movie
- Glacier Girl
- Appendix: GPR instrument (required to answer several questions)

Wave approach

GPR signals propagate through the Earth as wavefronts. However, we can use ray paths to represent the different ways in which GPR signals can travel from the transmitter to the receiver. Below we see the location of a wavefront at three different times and several ray paths.

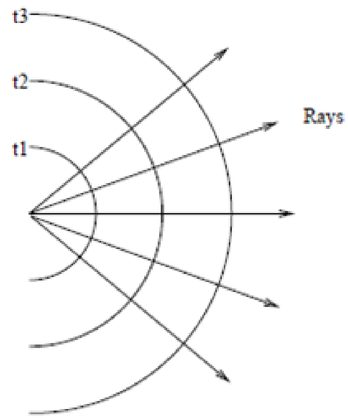

Figure 1: Conceptual diagram of wavefront and ray.

Watch the GPR Movie and look at the various wavefronts. Note that you can step through frame-by-frame using the arrows at the bottom (second and sixth buttons), or slow the frame rate using the minus-sign button on the left. In the GPR movie, Tx indicates the source location, and Rx with the red dots indicate receiver locations. No specific distances are provided and none are needed to answer the following questions.

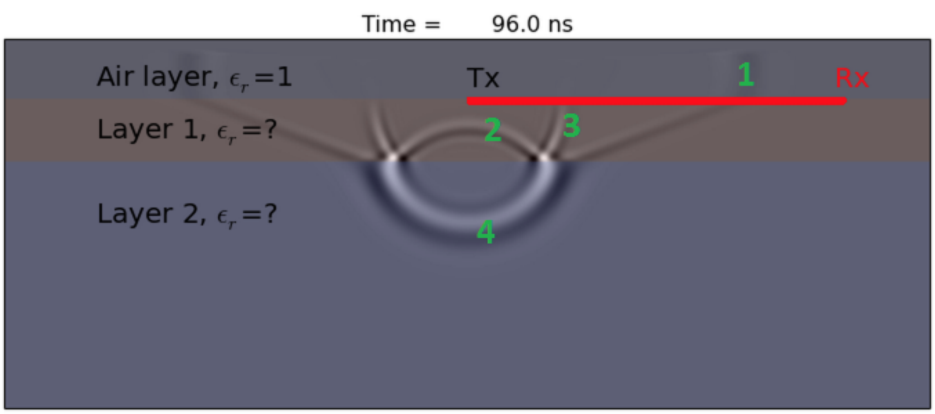

Figure 2: GPR wavefronts at 96 ns

1. What is the correct ordering of the wavefronts labelled in Figure 2?
   (a) (1) direct air wave (2) direct ground wave (3) reflected wave (4) transmitted wave
   (b) (1) direct ground wave (2) direct air wave (3) reflected wave (4) transmitted wave
   (c) (1) direct air wave (2) reflected wave (3) direct ground wave (4) transmitted wave
   (d) (1) direct air wave (2) transmitted wave (3) reflected wave (4) direct ground wave

2. Determine the velocity for layer 1 and use that to obtain the relative permittivity of layer 1. You can start by using the air wave velocity and travel time to get the length of the red line.
   (a) $v = 0.3$ m/ns. $\varepsilon_r = 1$.
   (b) $v = 0.1$ m/ns. $\varepsilon_r = 9$.
   (c) $v = 0.1$ m/ns. $\varepsilon_r = 3$.
   (d) $v = 0.2$ m/ns. $\varepsilon_r = 4$.

3. Which of the following statements are true?
   (a) The relative permittivity of layer 1 is larger than that of layer 2 because the propagation velocity is slower in layer 1 than in layer 2.
   (b) The relative permittivity of layer 1 is larger than that of layer 2 because the wavefront spreads out (refracts horizontally) as it enters layer 2.
   (c) The relative permittivity of layer 1 is smaller than that of layer 2 because the propagation velocity is slower in layer 1.
   (d) a) and b) are both correct.

4. Why is the thickness of the wavefront larger in layer 2 than it is in layer 1?
   (a) The propagation velocity is larger in layer 2, resulting in a longer wavelength.
   (b) The propagation velocity is larger in layer 2, resulting in a longer wavelength.
   (c) The central frequency of the GPR signal becomes smaller in layer 2, resulting in a longer wavelength.
   (d) The dielectric permittivity is larger in layer 2, resulting in a longer wavelength.

Case Study: Glacier Girl

Setup

5. What information was used to narrow down the survey area?
   (a) Information from detailed flight path documents
   (b) A radiowave signal transmitted by the aircraft
   (c) A preliminary geophysical survey
   (d) Historic photos and data on past ice movement

Physical Properties

6. Which physical is property is primarily response for making GPR ideal for glacial environments? Why?
   (a) Dielectric permittivity. The low dielectric permittivity allows GPR signals to propagate very fast.
   (b) Dielectric permittivity. The high dielectric permittivity results in better survey resolution.
   (c) Electrical conductivity. The skin depth for GPR signals is very small in glacial environments.
   (d) Electrical conductivity. The skin depth for GPR signals is very large in glacial environments.

Survey

7. What is the stated central operating frequency and vertical resolution of the system?
   (a) 50 MHz. 0.25 m.
   (b) 50 MHz. 0.5 m.
   (c) 100 MHz. 0.25 m.
   (d) 100 MHz. 0.5 m.

8. Assuming that ice has a relative permittivity of $\varepsilon_r = 4$, what is your estimation of the vertical resolution of the system? (Assume you are operating in the wave regime to compute the velocity)
   (a) 0.25 m
   (b) 0.5 m
   (c) 0.75 m
   (d) 1 m

Data

9. Can the GPR system described in the case study be used to collect both common offset and common midpoint data? Why?
   (a) No, because one antenna is used as both the transmitter and receiver.
   (b) No, because the transmitter and receiver use separate antennas.
   (c) Yes, because the transmitter and receiver use separate antennas.
   (d) Yes, because tne antenna is used as both the transmitter and receiver.

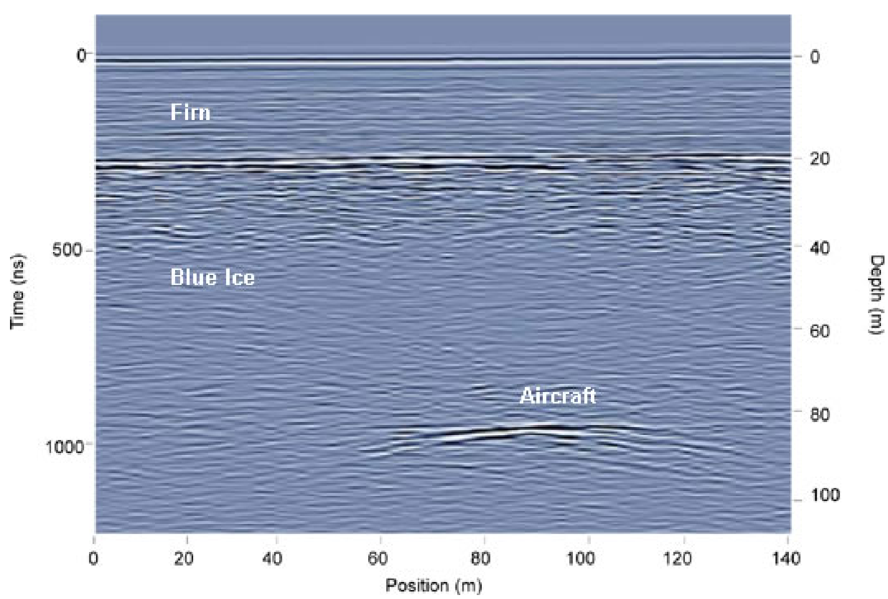

Figure 3: GPR section of the second case study.

Processing

10. The raw data were collected using a common offset configuration. Given the scale of the problem and the offset, the configuration can effectively be considered a zero offset. Note that the data has a vertical depth axis. However, we know that individual traces record the travel time. How could you convert the travel times to apparent depth?
    (a) First, assume a reasonable propagation velocity for the ice based on a known range of relative permittivities. Next, convert arrival times to apparent depths using the two-way travel time formula.
    (b) First, obtain the propagation velocity from the hyperbolic signature in the initial radargram image. Next, convert arrival times to apparent depths using the two-way travel time formula.
    (c) First, obtain the propagation velocity by using a point reflector model to fit the hyperbolic signature in the initial radargram image. Next, convert arrival times to apparent depths using the two-way travel time formula.
    (d) All of these approaches are reasonable depending on the accuracy required.

11. Officially, we have no information on how the authors performed the depth conversion. Let's assume they chose a constant velocity. If this is the case, (1) use figure 3 to estimate the velocity they used, then (2) calculate the corresponding relative permittivity.
    (a) $v = 0.18$ m/ns. $\varepsilon_r = 2.7$
    (b) $v = 0.09$ m/ns. $\varepsilon_r = 3.8$
    (c) $v = 0.09$ m/ns. $\varepsilon_r = 14.4$
    (d) $v = 0.18$ m/ns. $\varepsilon_r = 7.3$

Interpretation

12. Because of the transmitter-receiver offset, the receiver should measure both direct air waves and direct ground waves. Based on the scale of the problem, can the direct air and direct ground waves be differentiated in figure 3? Why/why not?
    (a) No. Because the attenuation in glacial enviornments is large and the amplitude of the direct ground wave is too small compared to the direct air wave.
    (b) No. Air and ice have similar dielectric permittivities (and thus velocities), so the arrival times of both waves are roughly the same.
    (c) Yes. Because the direct air wave always arrives before the direct ground wave.
    (d) Yes. Air and ice have sufficiently dissimilar dielectric permittivities (and thus velocities), so the arrival times of both waves are far enough appart.

13. How can we be certain that the hyperbolic signature observed in the radargram is from a buried aircraft?
    (a) Glacial enviornments are always comprised of homogeneous layered structures. Only the aircraft would result in a hyperbolic signature.
    (b) Because the apparent depth corresponding to the top of the hyperbola matches the known burial depth of the aircraft.
    (c) The dielectric permittivities of the air and ice are similar, thus any cavernous bodies would result in a weak reflector. We see a strong reflector in the data, which must correspond to a non-glacial object.
    (d) Although strong arguments may support the interpretation, we cannot be 100 % certain.

Synthesis

14. What is the primary reason why the survey was successful?
    (a) The laterial resolution of the survey at the depth of the aircraft was sufficient.
    (b) The vertical resolution of the survey of the survey was sufficient.
    (c) The low conductivity of ice resulted in a sufficiently large probing distance for the survey.
    (d) The shape of the aircraft could be distinguished directly from the radargram data.

Appendix: GPR instrument

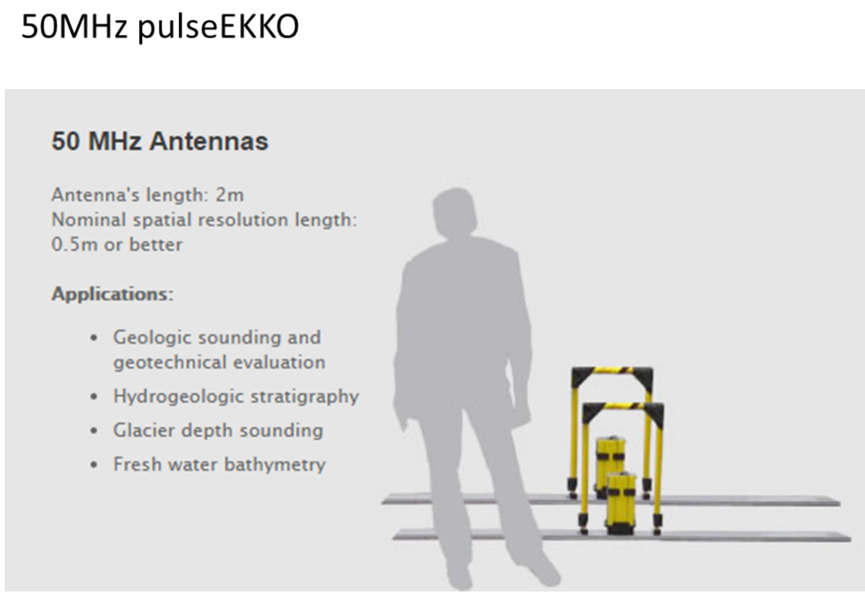

Figure 4: Sensors and Software 50MHz pulseEKKO description.