TBL # 4: Ground Penetrating Radar

DUE: Friday, October 25th, 2019

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.

In the first part of this exercise, you will explore the use of GPR in glacial environments. You are expected to read the Glacier Girl case history. Glacial environments represent a unique and important application of ground-penetrating radar. Questions in this part with focus on the 7 step framework.

In the second part of the exercsie, you will consider practical aspects of survey design for an example problem. Operating frequency, probing distance and resolution are considered using the **GPR Widget** (link in course schedule).

Instructions

Read the Glacier Girl case history and answer all multiple choice questions in part 1. Next, complete the multiple choice questions in part 2.

Resources

- GPG Geophysical Surveys: Ground Penetrating Radar
- GPR Movie
- Glacier Girl

PART 1: GLACIER GIRL CASE HISTORY

Setup

1. 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

2. 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

3. The central operating frequency of the instrument is 50 MHz. 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

4. 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 the antenna is used as both the transmitter and receiver.

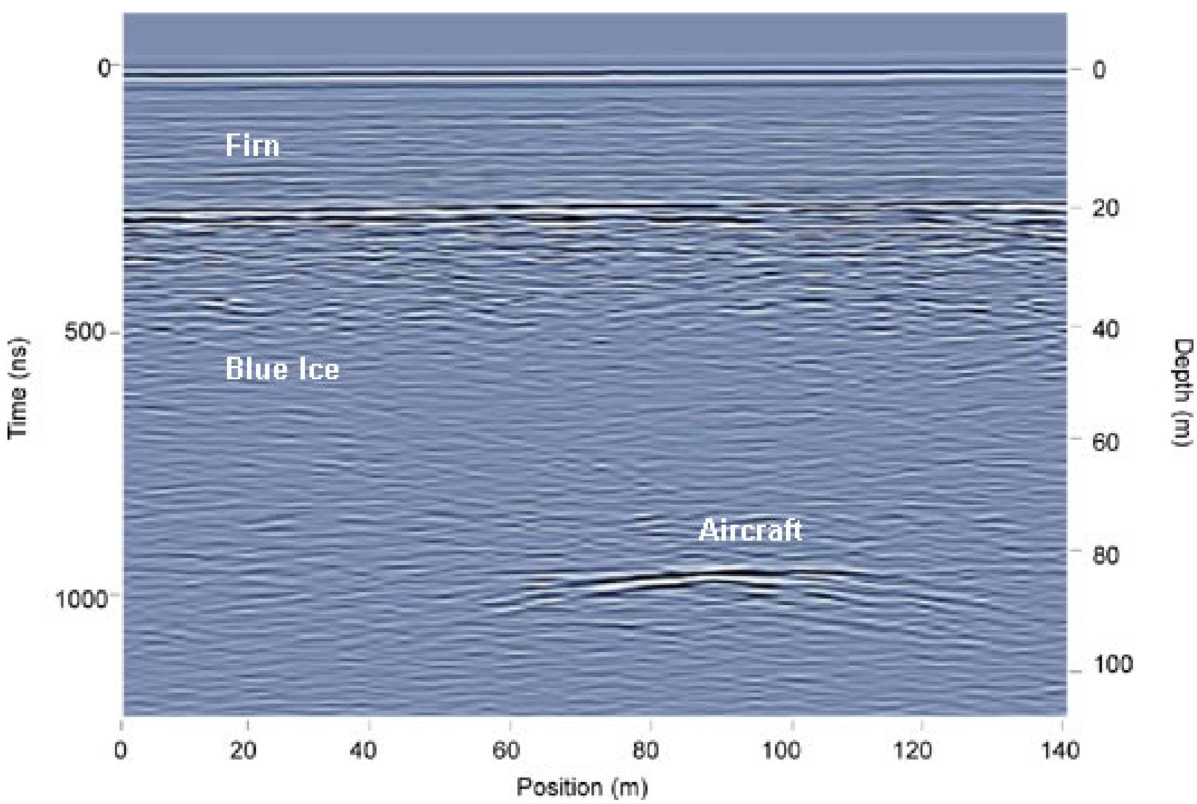

Figure 1: GPR section of the second case study.

Processing

5. 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.

Interpretation

6. 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 1? 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.

Synthesis

7. What is the primary reason why the survey was successful?
   (a) The lateral 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.

PART 2: SURVEY DESIGN, PROBING DISTANCE AND RESOLUTION

In order to maintain a water service pipe network in town, pipes under roads must be periodically dug up and replaced. Unfortunately, utility maps are frequently out of date. Knowing the precise location and depth of each pipe is important, as buried gas lines and electrical wires can pose as serious hazards. You are tasked with using GPR to locate a set of buried utilities (Figure 2), including:

- a pair of electrical utility wires/pipes, thought to be buried between a depth of 20cm and 50cm.
- a water pipe. The top of the pipe is known to be between 1 and 2 metres below the surface. The pipe has a known diameter of 1 m.

Your objective is to design a survey which 1) has a sufficient probing distance, 2) provides a sufficient resolution for the objects you want to find and 3) produces GPR signatures which are easy to interpret.

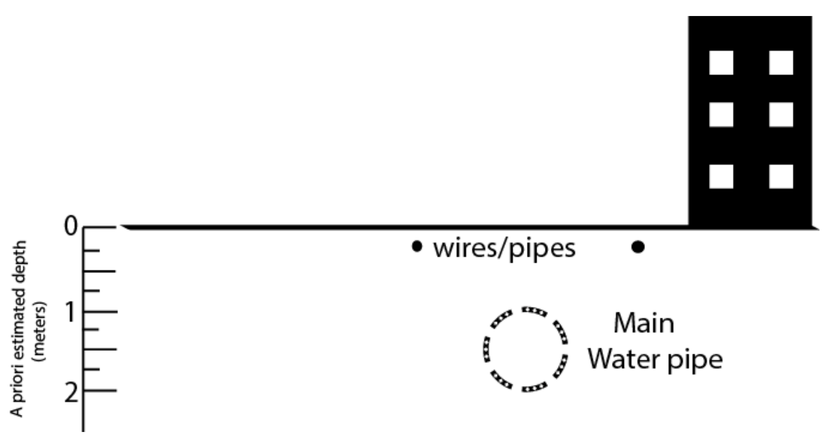

Figure 2: Sketch of the area to survey

Survey design

Here, we will consider the transmitter-receiver configuration, orientation and other aspects of survey design for the problem illustrated in Figure 2. Decisions made here will ultimately determine the types of signatures which present in the resulting radargram data.

8. Given the known orientation of the pipes and wires in Figure 2, how would you orient your acquisition line?
   (a) Parallel to the pipe/wires
   (b) Perpendicular to the pipe/wires
   (c) Either way is fine

9. Assume the GPR system you are using is not shielded, and that the reflection off a nearby building is observed (see Figure 2). What shape would the corresponding radargram signature have if the acquisition line were perpendicular to the building? (assume a zero offset survey is being used)
   (a) Linear
   (b) Hyperbolic
   (c) Flat middle with hyperbolic edges
   (d) None of the above

10. Which of the following is **not** useful information to be considered when choosing an operating frequency?
    (a) An estimate of the depth to your target.
    (b) The physical properties of the host media.
    (c) The dimensions of the target.
    (d) All of the above must be considered.

Probing Distance and Resolution (wave regime)

GPR uses radiowave signals which are very high frequency. As a result, many characteristics of GPR signals, such as propagation velocity and skin depth, may be approximated by the "wave regime". Here, the cell containing **WidgetWaveRegime()** is used to investigate how probing distance (depth of investigation) and resolution depend on electrical conductivity, relative permittivity and operating frequency. The fundamentals learned here will assist in determining optimum survey parameters for the problem illustrated in Figure 2.

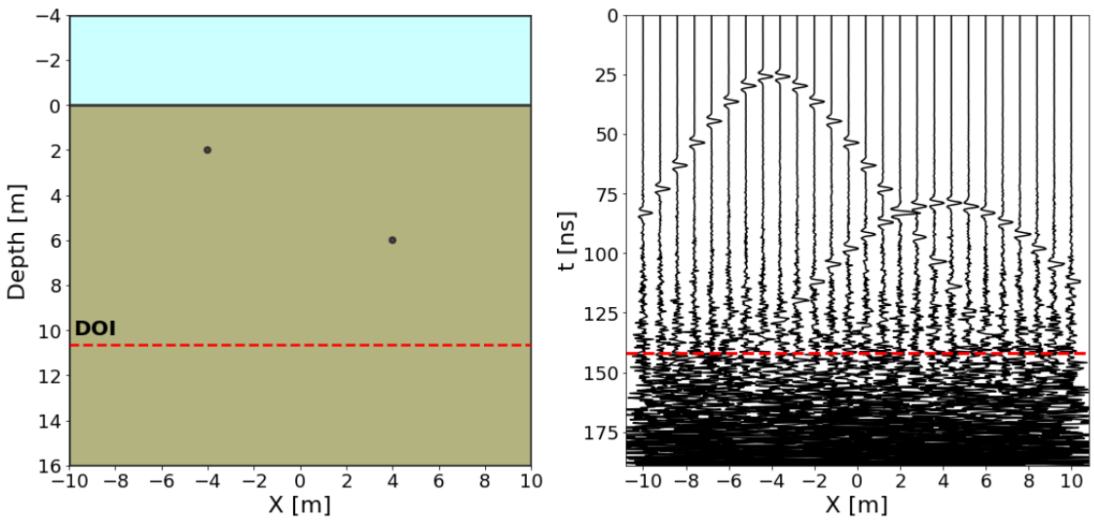

Figure 3: Screen shot of the GPR zero offset app.

Using the **GPR zero offset app**, answer the questions below regarding probing distance (DOI) and resolution in the wave regime. The following information may be useful:

- In the wave regime, the propagation velocity is equal to $v = \dfrac{c}{\sqrt{\varepsilon_r}}$
- The probing distance (depth of investigation) is equal to 3 skin depths ($DOI = 3\delta$)
- The horizontal resolution is approximately equal to $L = \sqrt{\dfrac{vd}{2f_c}}$

11. Using the default settings on the GPR zero offset app, what is the skin depth for the Earth?
    (a) 16 m
    (b) 10.8 m
    (c) 3.6 m
    (d) 1.8 m

12. Change the location of object 1 to (x_1, d_1)=(0m, 6m). Now slowly decrease the value of x_2. Note the distance at which object 1 and object 2 no longer be differentiated. Use the current set of parameters to compute the horizontal resolution. What is the approximate calculated horizontal resolution?
    (a) 0.5 m
    (b) 1.25 m
    (c) 1.75 m
    (d) 2.5 m

13. Slowly increase the relative permittivity of the Earth from 4 to 9. Which of the following occurs?
    (a) The probing distance increases.
    (b) The horizontal resolution improves.
    (c) The wavelength of the GPR signal decreases.
    (d) All of the above

14. Reset the widget to default parameters (select cell and press Shift+Enter). Slowly increase the electrical conductivity from 3 mS/m to 5 mS/m. Why is the hyperbolic signature from object 2 no longer visible?
    (a) The object is past the limit of the probing distance.
    (b) The signal to noise ratio is too small from object 2 is too small.
    (c) a) and b) are correct.
    (d) a) and b) are incorrect.

15. Gradually increase the central operating frequency beginning from 250 MHz. Does the probing distance change? Why/why not?
    (a) No, because probing distance is independent of frequency in the wave regime.
    (b) No, because the relative permittivity of the Earth is small.
    (c) No, because the electrical conductivity of the Earth is large.
    (d) No, because the probing distance is less than 16 m

Probing Distance and Resolution (general)

Here, we will use the cell with **AttenuationWidgetTBL()** to consider an appropriate operating frequency for the survey illustrated in Figure 2. Unlike in the previous part, we will **not** be using the wave regime approximation for skin depth and propagation velocity; these quantities are computed by the app at f_c = 25, 100 and 1000 MHz. The following information may be useful:

- The probing distance (depth of investigation) is equal to 3 skin depths ($DOI = 3\delta$)
- A good estimate for the vertical layer resolution is $L = \sqrt{\dfrac{vd}{4f}}$.
- $\log(0.0316 \text{ S/m}) = -1.5$

16. Using a transmitting frequency of 25 MHz, if the background conductivity is 0.0316 S/m (note that $\log(0.0316) = -1.5$S/m) and the relative permittivity is $\varepsilon_r = 9$, what is the probing distance?
    (a) 0.58 m
    (b) 0.88 m
    (c) 1.74 m
    (d) 2.68 m

17. Based on your previous answer, is the probing distance large enough to image both the electrical utility wires/pipes and the water pipe as shown in Figure 2?
    (a) No
    (b) Yes

18. Using an operating frequency of 100 MHz, if the background conductivity is 0.1 S/m and the relative permittivity is $\varepsilon_r = 9$, what is the vertical layer resolution? (Use the velocity computed in the app)
    (a) 0.10 m
    (b) 0.16 m
    (c) 0.25 m
    (d) 0.32 m

19. Using the parameters from the previous equation, compute the vertical layer resolution assuming you are in the wave regime (i.e. neglect the electrical conductivity when compute the velocity). Does the wave regime approximation overestimate/underestimate the true vertical layer resolution?
    (a) 0.10 m. The wave regime approximation overestimates the vertical layer resolution.
    (b) 0.16 m. Both estimates would have been approximate.
    (c) 0.25 m. The wave regime approximation underestimates the vertical layer resolution.
    (d) 0.32 m. The wave regime approximation underestimates. the vertical layer resolution.

20. The app demonstrates how propagation velocity and skin depth depend on operating frequency. By examining the curves, which of the following is true?
    (a) In general, the propagation velocity and probing distance increase as a function of frequency.
    (b) Propagation velocity and probing distance are independent of frequency in the wave regime.
    (c) a) and b) are correct
    (d) a) and b) are incorrect