Lab 6: GPR

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Overview

During ground penetrating radar (GPR) surveys, an antenna is used to send a pulse of radiowaves into the Earth. As the GPR signal propagates, it is reflected, transmitted and refracted at interfaces where the Earth's electromagnetic properties change. Some of the GPR signal returns to the Earth where it is measured by a receiver.

In this lab, you will consider the signals which propagate through a two-layer Earth. For several models, you will also consider the ray paths which reach the receiver, and infer the signatures which present in the corresponding radargrams. Finally, you will interpret radargram data collected at UBC.

Running the iPython Notebook

For this lab, you will not have to write any code. You will only be running it.

- *Shift + Enter* runs the code within the cell (so does the forward arrow button near the top of the document)
- You can alter variables and re-run cells by changing the values and doing *Shift + Enter*
- If you want to start with a clean slate, restart the Kernel either by going to the top, clicking on *Kernel: Restart*, or by *esc + 00*

Resources

- GPG: GPR Section
- Zip File containing the notebook

Identifying the Ray Paths of GPR Signals

Consider the model shown in Figure 1. This model consists of three layers: air, layer 1, and layer 2. The layers have relative permittivities $\epsilon_{r,air}$, $\epsilon_{r,1}$ and $\epsilon_{r,2}$ respectively. The distance between the source and the receiver is given by x. The source and receiver antennas are oriented in y-direction.

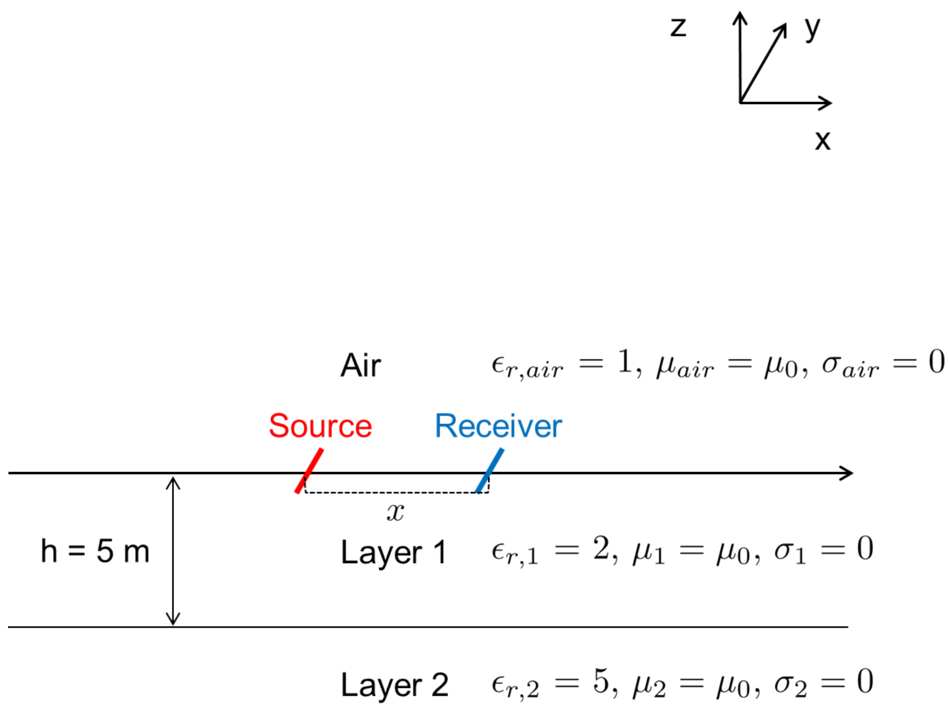

Figure 1: Conceptual diagram of GPR source antenna and receivers.

Q1. For the model shown in Figure 1, there are a number of ways in which portions of the GPR wavefront (or waves) can reach the receiver. The different travel paths are called ray paths. Answer the following questions about GPR signals and ray paths.

a. There are two direct paths which GPR signals can take from the transmitter to the receiver. Where do each of these waves propagate? Sketch the two ray paths on your own diagram below.

A: direct air wave and direct ground wave

b. Which of the two direct signals will arrive first? Justify your answer by considering the physical properties of each medium.

A: air wave, $v = c/\sqrt{(}\epsilon_r)$ when $\mu_r = 1$, and $\epsilon_{r,air} < \epsilon_{r,1}$ always

c. If the transmitter and receiver are separated by a distance x, what is the expression for the travel time for a direct wave?

A: t = x/v, where v = c/sqrt(eps)

d. Suppose the operating frequency of the GPR system is 200 MHz. What is the spatial length (wavelength) of the GPR wavelet as it travels through the ground. Assume the ground has a relative permittivity of $\varepsilon_r = 4$. Sketch a typical wavelet below.

A: $\lambda = c/f_c\sqrt{\varepsilon_r} = 0.75$ m

e. For layer 1, what is the smallest separation distance which two buried object could have and still be visible with a zero-off survey? Assume the objects are buried at a depth of 4 m. The operating frequency is still 200 MHz.

A: $D > \sqrt{\frac{Vd}{2f_c}} = 1.22$ m

f. Plot the radargrams for the direct air wave and direct ground wave on the t-x plot in Figure 2. Recall that we know the relative permittivity of air and that the relative permittivity of layer 1 is $\varepsilon_r = 4$.

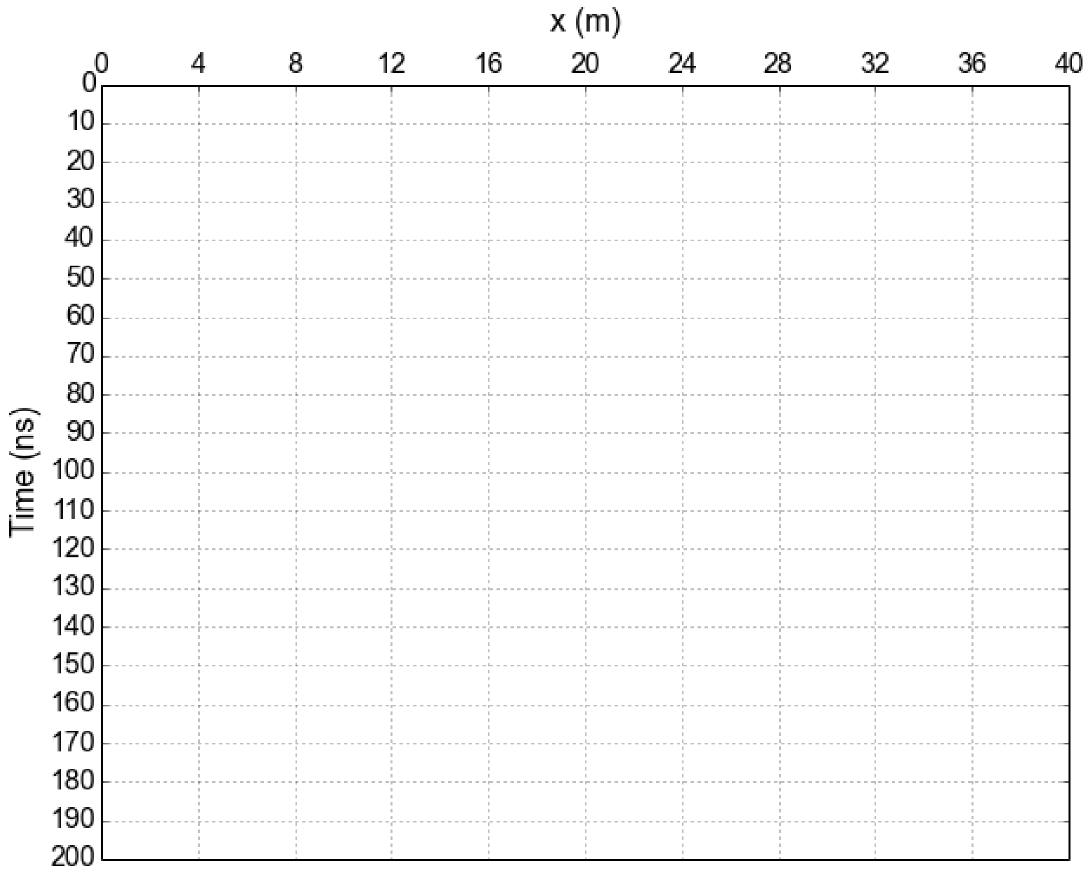

Figure 2: T-X plot

g. When the GPR signal sent into the Earth reaches the interface between layers 1 and 2, some of it is reflected and some of it is refracted.

(i) Add the reflected ray path to your diagram in Question 1a.

(ii) The formula for the travel time as a function of offset is given by $t = \sqrt{(x^2 + 4h^2)}/v_1$. Use this forumla to fill in the table below.

(iii) Add the reflected wave signal to the T-X plot in Figure 2.

x (m)	arrival time from the reflected wave at 1st interface (t)
0	
1	
2	
4	
8	
16	
24	

A: 67 ns, 67 ns, 68 ns, 72 ns, 85 ns, 126 ns, 173 ns

h. For the geologic model we are considering, is it possible for there to be a critically refracted wave? Along which interface would the critically refracted wave travel if possible? Explain.

A: Yes. It would travel along the surface interface. Because $V_{air} > V_1$ always.

i. Given that $\varepsilon_{air} = 1$ and $\varepsilon_1 = 4$, what is the angle for the critical refraction at the surface.

A: $\theta_c = \sin^{-1}(v_1/v_{air}) = 30$ degrees

j. At what offset (x_c) will the critically refracted ray first be detected by receivers at the surface? Add the critically refracted wave to the T-X plot in Figure 2.

A: $x_c = 2h \tan\theta_c = 5.77$ m

Sketch ray paths on a profile line

In this section, we sketch ray paths for the GPR survey configurations and models provided. By drawing the ray paths, we can then infer the features we would expect to see in the corresponding radargram.

Q2. Consider the thick slab model in Figure 3. Let the black dots represent the Tx-Rx locations for a **zero offset** configuration.

a. Sketch the reflected ray paths for the slab model given below. Recall that rays which reflect off a point will reflect in all directions.

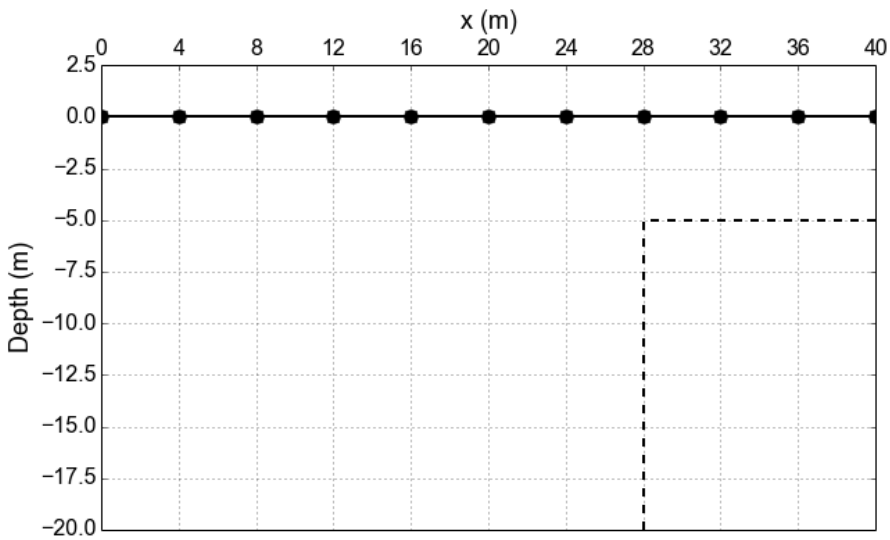

Figure 3: Ray paths for the slab model.

b. If the slab was very thin (a horizontal pancake), would the ray paths change? Why?

A: No. None of the reflected waves from the vertical face will reach a receiver.

c. Based on ray paths you drew on Figure 3, sketch the corresponding radargram on the figure below. You will first need to determine the top-layer velocity. This can be done by looking at the arrival time to depth conversion between Figures 3 and 4. Assume that it takes 200 ns for a reflected signal at 20 m depth to return.

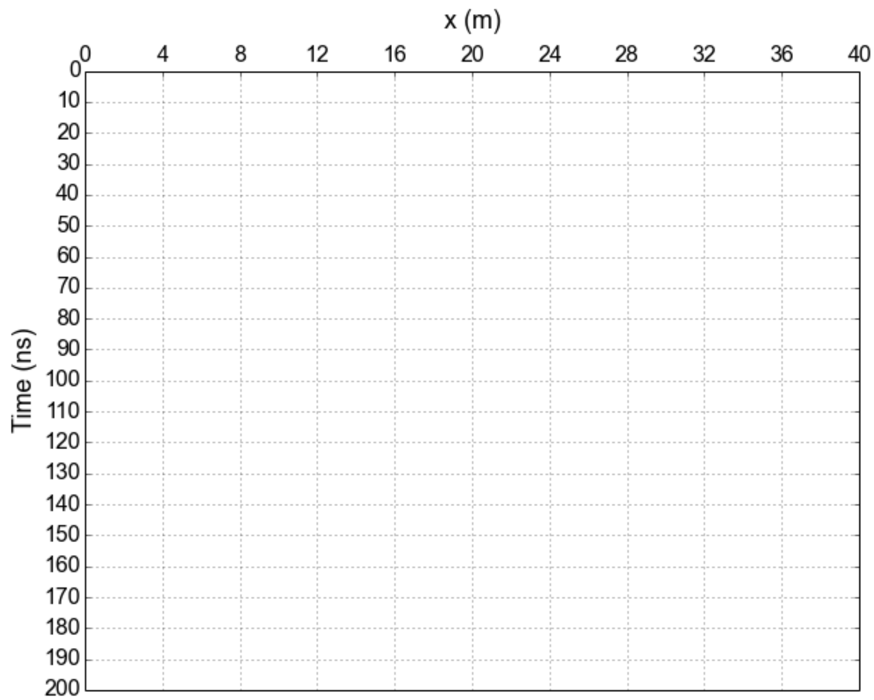

Figure 4: Arrival times for the slab model

Q3. Consider the concave interface in Figure 5. Once again, we will use a zero offset survey configuration.

a. Sketch the reflected ray paths for the interface given below when the GPR unit is at x=8, x=16 and x=20m

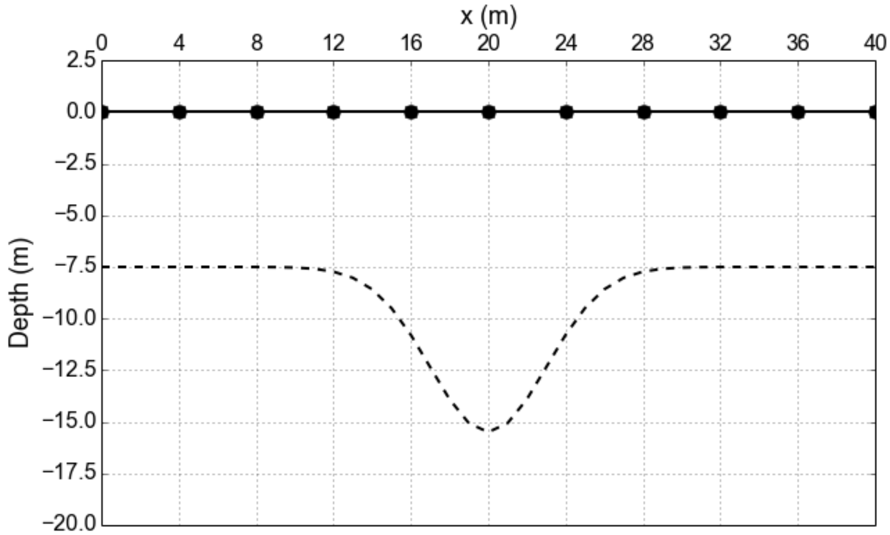

Figure 5: Ray paths for the syncline model

b. Why might it be more difficult to infer the shape of this interface from radargram data?

A: Because we will see multiple reflected signals for the same interface.

Interpretation of Field Data

In this section, we will interpret field collected GPR data collected at the University of British Columbia. Applications in the GPRWidget will help you answer subsequent questions. **For all remaining questions, we will only be using Step 4a and Step 4b in the GPRWidget.**

Q4. Consider the radargram data shown in Figure 6. These data were collected using a zero offset survey. Let us assume we know there are three different types of objects present:

- Layered interfaces
- Buried pipes
- A concrete utility casing

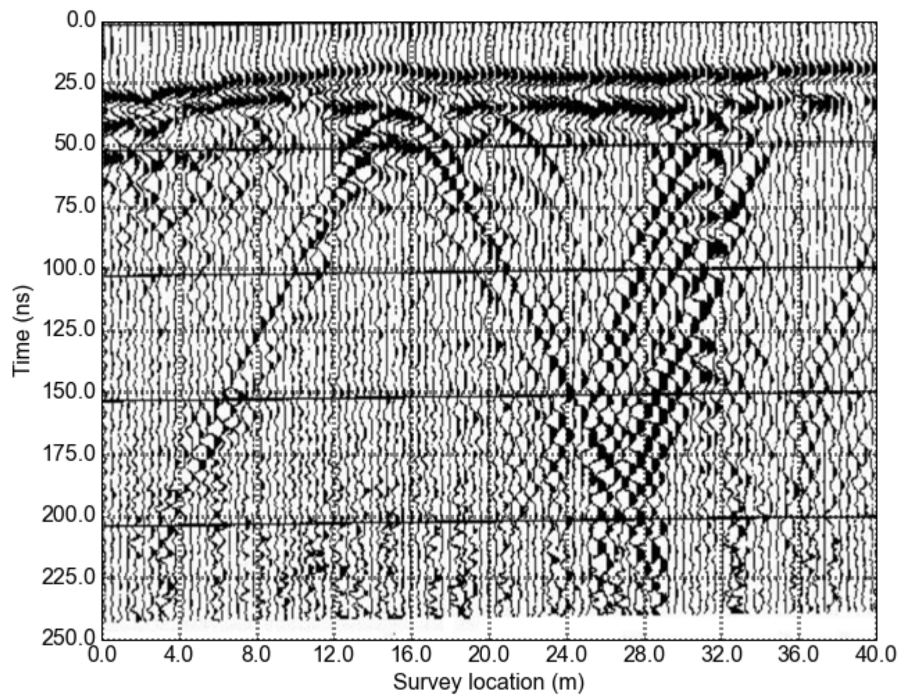

Figure 6: Common offset profile collected by UBC

a. On Figure 6, identify the signatures attributed to buried pipes on the radargram (there are two).

b. Using the GPRWidget, fit the left-most signature by adjusting the parameters provided: epsr (relative permittivity), h (distance of the pipe center from the surface), xc (the pipe center location), r (radius of the pipe). Record the parameters you used.

A: epsr = 23, h = 1.8, xc = 15.6, r = 1.2

c. Now fix the radius and depth to the pipe as r = 0.5 m and h = 1.5 m, respectively. Are you able to fit the left-most pipe by adjusting only epsr and xc? Write down the relative permittivity and centre location which gave you the best fit.

A: epsr = 23, xc = 15.6

d. Try using parameters: epsr = 28, h = 1.7, xc = 15.4 and r = 0.7. Do these parameter value fit the signature from the pipe reasonably well? Therefore, is there a unique set of parameter values which fit the data or is the solution "non-unique"?

A: Yes. The solution is non-unique.

e. Based on your answer to the previous question, answer the following. (i) Is the set of parameter values which fit the data always always correspond to the correct answer? (ii) If a set of parameter values does not fit the data, can it be ruled out as a potential solution?

A: No. Yes.

f. Set the parameter values to: epsr = 28, h = 1.5, xc = 15.4 and r = 0.4. Now slowly increase the radius of the pipe to 3 m and examine how the curve is changing. Note that as you increase the radius of the pipe, it stops being a point reflector. (i) Is the slope of the "tails" of hyperbolic signature changing as you increase the radius? (ii) Can we use the slope to estimate the top layer velocity if the pipe is thick?

A: No. Yes.

g. On Figure 6, draw a line where you are observing the reflection from a layer boundary. Using the parameters from your answer in **b)**, estimate the top layer velocity and approximate the depth to the chosen reflector. Show the equations you used.

A: $V = c/\sqrt{\varepsilon_r} \sim$ .063 m/ns. $D = 1/2 \times 25ns \times 0.63m/ns \sim$ 7.9 m.

h. Identify the response due to the large concrete casing. Label where you think the concrete casing is on Figure 6. Hint: the shape of the signature should be **very** similar to that of the slab in **Q2**.

i. Using the GPRWidget, fit the signature you chose by adjusting the parameters for the slab. Record the parameters that you find.

A: ...

j. When the transmitter and receiver are located at roughly 30 m along the profile line, notice that a signal persists over most of the observation times. Both the pipes and the concrete casing are strong conductors (great reflectors). (i) If one of the pipes is very near to the concrete casing, what might be causing this signal? (ii) Did the effects of this signal make it more difficult to locate the left-most margin of the concrete casing?

A: Ringing. Yes.