Lab 6: GPR

TA: Seogi Kang
e-mail: skang@eos.ubc.ca
office: ESB 4037

DUE: Before your next lab session

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 GPR signals which correspond to several basic scenarios. First you will characterize the signals which result from a two-layer Earth model. For several models, you will sketch the ray paths which are expected to reach the receiver, and infer the signatures which present in the corresponding radargrams. Finally, you will interpret radargram data collected at UBC.

Running Jupyter Notebook from gpgLabs

- *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
- Jupyter Notebook: GPR Lab6 FitData.ipynb

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.

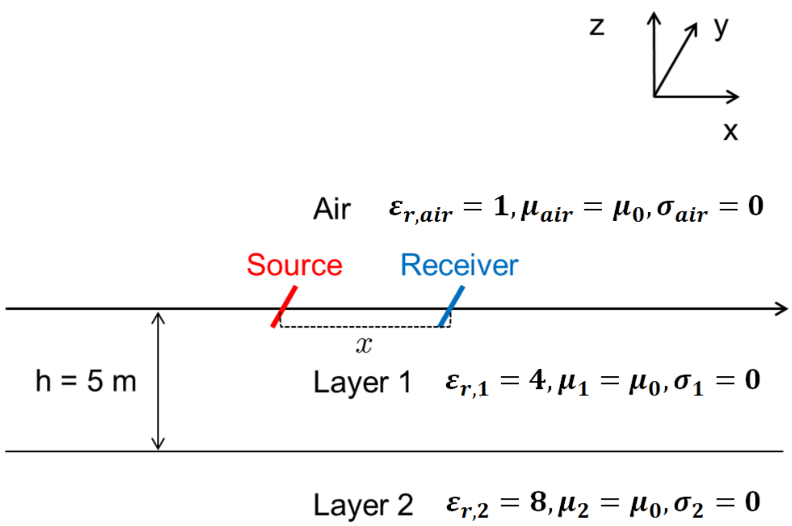

Figure 1: Conceptual diagram of GPR source antenna and receivers.

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 along which GPR signals can travel from the transmitter to the receiver. What is the name given to each of these waves? 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 layer 1? Recall that $\varepsilon_{r,1} = 4$. Sketch a Ricker wavelet below.

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

e. For layer 1, what is the smallest separation distance (horizontal resolution) two buried objects could have and still be distinguishable using a zero-off survey? Assume the objects are buried at a depth of 4 m. The operating frequency is still 200 MHz.

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

f. Plot the radargram signatures for the direct air wave and direct ground wave on the t-x plot in Figure 2. The transmitter location is fixed at $x = 0$ m. The receiver location is being moved from $x = 0$ m to $x = 40$ m. Recall that we know the relative permittivity of air and that the relative permittivity of layer 1 is $\varepsilon_{r,1} = 4$.

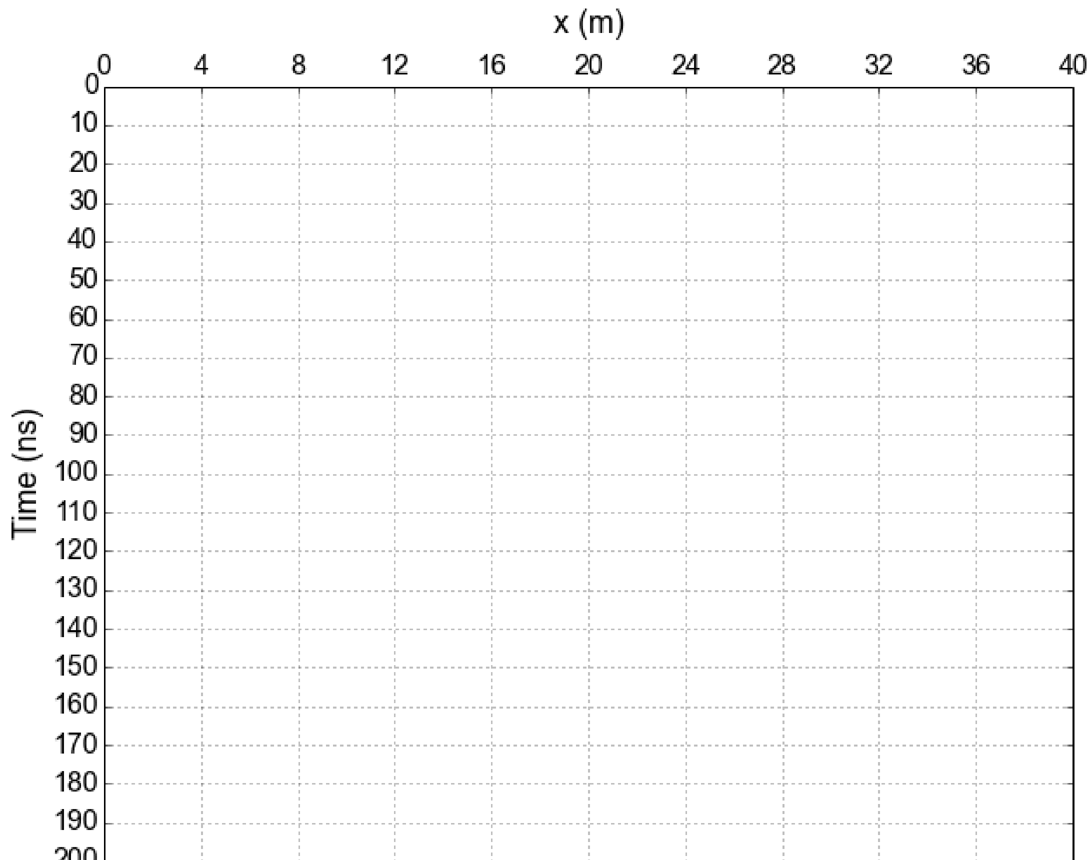

Figure 2: T-X plot

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

(i) Sketch the reflected ray path on your diagram from Question 1a.

(ii) The formula for the reflected wave 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) Using the values from your table, 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, there is a critically refracted wave. Along which interface does the critically refracted wave travel? Briefly explain your reasoning.

A: It travels along the surface. Since $V_{air} > V_1$ always, some of the reflected signal from the layer 1 layer 2 interface is critically refracted.

i. Given that $\varepsilon_{r,air} = 1$, $\varepsilon_{r,1} = 4$ and $\varepsilon_{r,2} = 8$, what is the critical angle for your critically refracted wave?

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. Draw only the ray paths that reach receivers.

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.

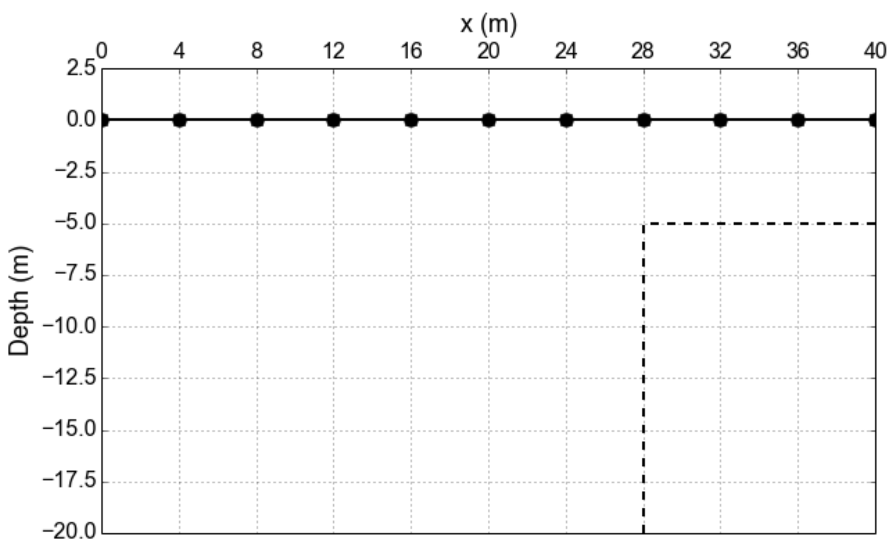

Figure 3: Ray paths for the slab model.

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.

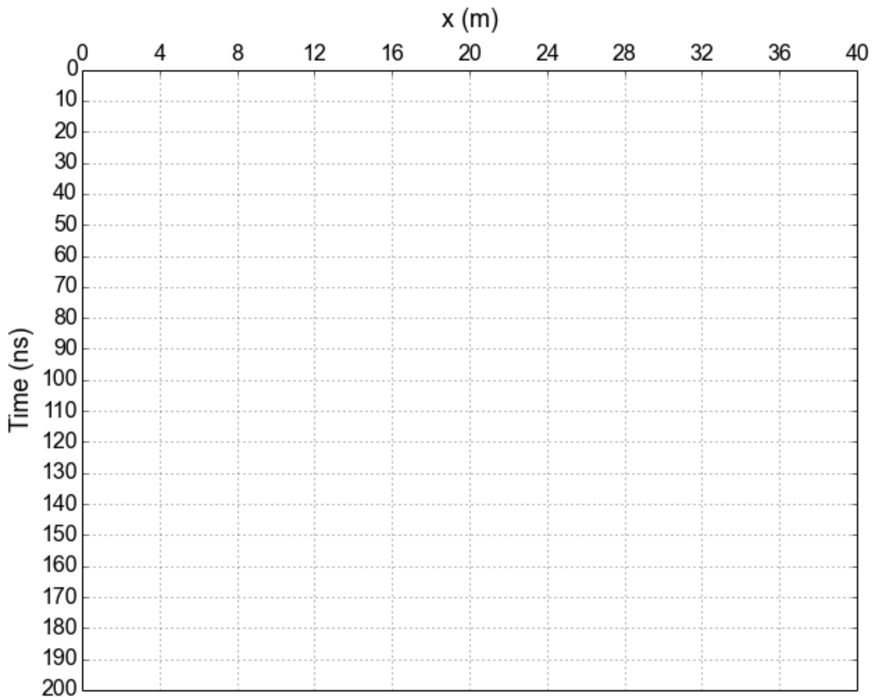

Figure 4: Arrival times for the slab model

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

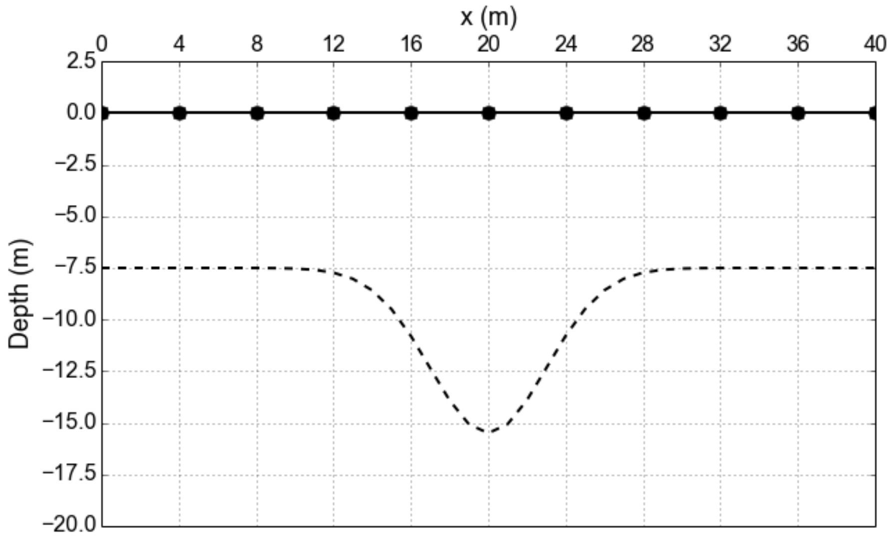

Figure 5: Ray paths for the syncline model

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. Data were collected over several utility pipes and a large concrete casing using a zero offset configuration (Figure 6). Here, you will use apps within the **GPR Lab6 Data Fit Notebook** to fit field collected data and infer information about the buried objects.

Q4. With the help of the **GPR Lab6 Data Fit Notebook**, answer the following questions.

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

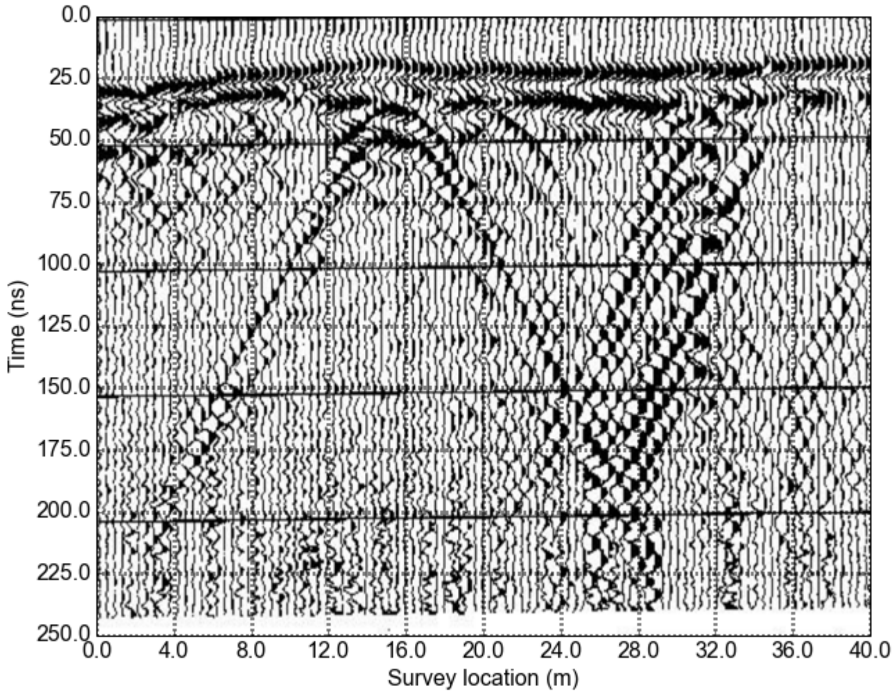

Figure 6: Common offset profile collected at UBC

b. Using the **Pipe Fitting App**, fit the left-most signature by adjusting the parameters provided: epsr, h, xc and r. 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 values 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 (Yes/No)? (ii) If a set of parameter values does not fit the data, can it be ruled out as a potential solution (Yes/No)?

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 (Yes/No)? (ii) Can we use the slope to estimate the top layer velocity if the pipe is thick (Yes/No)?

A: No. Yes.

g. On Figure 6, what geological feature corresponds to the consistent radargram signature at t = 25 ns? In what way might the model used to simulate responses from pipes be incorrect in this case?

A: A horizontal reflector. The model assumes a homogeneous relative permittivity for the background.

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 **Slab Fitting App**, 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 (Yes/No)?

A: Ringing. Yes.