

Lab #9. Seismic event location in classroom

In this lab, you will produce several “seismic events” on the floor of room Geology 265 and try determining their times and locations by using seismic arrivals. This experiment will be a miniature model of how earthquakes are located in real Earth settings:

- on the global scale,
- regionally (within about 1000 km distances from seismic stations),
- locally (within about 150 km),
- at the scale of a mine or fluid injection site (scale of about 0.1 – 1 km),
- and all the way to the scales of acoustic-emissions experiment with rock cores (~10 cm).

You will:

- examine the waveforms at different locations on the table and relate them to the structure of the “subsurface”;
- compare the waveforms produced by different sources and measure their spectra;
- estimate the wave speed within the table;
- apply filtering and deconvolution to the records.

In labs #9 and #10, we will utilize the experience from this lab to conduct different types of seismic experiments on the floor of this classroom: seismic event location, Vibroseis recording, surface-wave dispersion analysis, and with some luck, try “passive” noise recording.

Theory

Seismic location is performed for each event independently and based on minimizing the misfit between the observed travel times and those predicted from the model. In a 2-D case (only the epicenter¹ coordinates (x_s, y_s) are unknown and the hypocenter depth is approximated as equal zero), the predicted times are:

$$t_i = t_s + \frac{\sqrt{(x_i - x_s)^2 + (y_i - y_s)^2}}{V}, \quad (1)$$

EOL_____

¹ For earthquakes, epicenter is the point on the surface of the Earth located above the hypocenter. Hypocenter is the point below the surface at which the displacement of the crustal blocks occur.

where $i = 1, \dots, N_{st}$ is the station number, (x_i, y_i) are the coordinates of i -th station, t_s is the time of the source, and V is the wave velocity.

In equations (1), the source coordinates (x_s, y_s) and time t_s are unknown and need to be found from conditions that the predicted times at each station matches the observed time:

$$t_i = t_i^{observed} . \quad (2)$$

Equations (2) for each station cannot generally be satisfied by varying only three unknowns, and therefore they are solved in an approximate sense, by minimising the total squared travel-time data misfit:

$$\Phi(x_s, y_s, t_s | V) = \sum_i (t_i^{observed} - t_i)^2 = \sum_i \left[t_i^{observed} - \left(t_s + \frac{\sqrt{(x - x_i)^2 + (y - y_i)^2}}{V} \right) \right]^2 . \quad (3)$$

This function of variables (x_s, y_s, t_s) (assuming V known) is called the objective function, cost function, or penalty function. The best source location (x, y) is the one minimizing this objective function.

For simple problems like the one in this lab, the optimum values of unknowns can be found by computing function (2) at all grid points of interest, contouring it or using color displays, and finding its minimum. However, the approach in eq. (3) still has a problem, which is the need to know the value of V prior to evaluating function $\Phi(x_s, y_s, t_s)$. These variables could be included in grid search, but the grid would become 4-D and very computationally expensive. The search might also become unstable if times are insufficiently accurate (due to noise or scattering) and location problematic because of poor station coverage.

To overcome the above problems, we use a “supervised” method in which the source coordinates (x_s, y_s) are tested independently by an analyst (you) with the help of interactive software. For any pair of trial (x_s, y_s) , distances from the source to each station are calculated, and t_s and $1/V$ can be obtained from linear regression (function `polyfit` in Matlab) of all data $\{t_s^{(i)}\}$ considered as a function of the source-receiver distance:

$$t_i = t_s + \frac{1}{V} \sqrt{(x_i - x_s)^2 + (y_i - y_s)^2} . \quad (4)$$

Sometimes (when the event has poor distance coverage), this regression is also insufficiently stable. In such cases, we can set a fixed value of V and only estimate the source time:

$$t_S = \frac{1}{N_{st}} \sum_{i=1}^{N_{st}} t_S^{(i)}, \tag{5}$$

where $t_S^{(i)}$ is the source time estimated from a single arrival time t_i :

$$t_S^{(i)} = t_i - \frac{\sqrt{(x_i - x_S)^2 + (y_i - y_S)^2}}{V}. \tag{6}$$

In the software, trial values for (x_S, y_S) are set by simply clicking on the map of the survey area (Figure 1). The program then re-calculates parameters V and t_S and displays function $\Phi(x_S, y_S, t_S)$ (eq. 3) in color. The correct location (small time error) is shown in this image by light colors (white) and the best

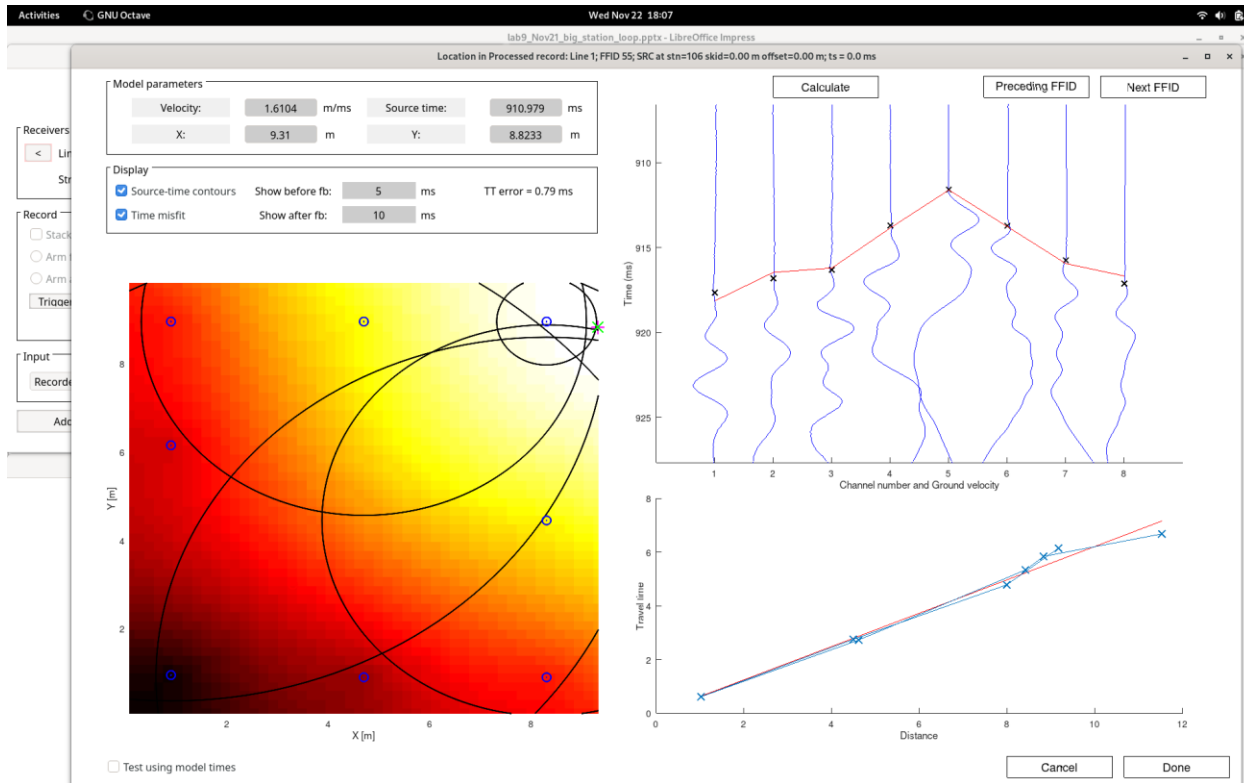


Figure 1. Sample display from the location program used in this lab.

location is indicated by a magenta plus symbol (Figure 1). The travel-time fit in eq. (4) is also shown, so that you can evaluate the quality of velocity estimation, and the overall travel-time error (equal

$\sqrt{\frac{1}{N} \Phi(x_s, y_s, t_s | V)}$ is indicated on the display. Thus, our goal is to achieve the smallest overall travel-time error and the most linear appearance if the time(distance) display in the lower-right corner of Figure 1.

The principle of source location is also illustrated in the display by black circular arcs drawn on the map (Figure 1). These arcs are centered at each station i and the radius of the i th arc equals $r_i = (t_i - t_s)V$. Therefore, the i th arc shows all possible locations of the source which would satisfy the arrival time t_i observed at this station. The correct source location is where all of these curves come together.

The red line in the upper-right panel of the display is another quality control of the location procedure (Figure 1). This curve shows the arrival times predicted by the model. The arrival times can be repicked in this panel, which will change the appearance of all displays.

Things to do

We will conduct two seismic location experiments in classroom 265: one with eight stations located around the perimeter of the room, and one with a smaller loop of stations placed around the center of the room.

Data acquisition

- 1) **Place the 8 receivers along the perimeter of the room:** four stations at the corners and four stations near the middles of each wall. Plan several source points (mark them with chalk or something else). Use measuring tape to **measure the coordinates** of all receivers and source points. **Sketch the layout in your workbook** and provide the coordinates for entry in the recording computer.
- 2) **Use a hammer** to strike at every source point and make recordings as in the previous lab. Create **screen captures** of the records.
- 3) **Repeat the same source points** with another type of source. For example, stomp feet at the marked locations.
- 4) **Repeat recording again using vibrator** at one or two source points. Use 100-1000 Hz upswing with 10-sec duration. This test should be recorded in a different project in the computer, so that changing the duration of the records does not complicate visualization and data analysis.

- 5) **Move the receivers into a smaller loop layout** of about $\frac{1}{2}$ of the room length and width. Now some sources should be located outside of the station network. Create yet another project in the recording software and set short (e.g., two-second) recording time windows. **Measure coordinates of the receivers** and enter them in the software.
- 6) **Repeat steps 2) and 3) with the new locations of stations.**

Data analysis

- 7) Look through the recorded records in the seismograph software. **Compare the records from hammer and “stomper” sources.** Use the spectral analysis tool (“Processing” -> “Current Record” -> “Spectra and Export”) to **compare the spectra of the sources. Which of these sources gives better first arrivals?**
- 8) Use “Processing” -> “Current Record” -> “Edit and Pick...” tool to pick the first arrivals for the selected type of sources. This tool can also be used for shifting the time origins of the records and for editing (“killing”) bad records. We should not need these options though.
- 9) Use “Processing” -> “Current Record” -> “Locate” tool to **locate the sources for each record.** How well do they correspond to the known locations? **Write down in your report** the source times t_s and the estimated velocities V . Are the values of V close when estimated from different sources?
- 10) **Compare location accuracy** for different sources. In which directions and in which parts of the room (center, corner) locations are more accurate? Semi-quantitatively, this can be seen from the appearances of the images of the objective function (eq. 3).
- 11) **Compare the location accuracy for the sources located inside and outside of the receiver station network.** You should see that sources outside of the seismic network are located much less accurately.
- 12) This is experimental and may not be ready in time for the lab: **Transform the long vibrator sweep records into source-receiver time delays** at 1-2 frequencies, and **use these time delays for locating the sources.** Compare the location, values of V , and location accuracy with the preceding test results.

Hand in:

Zipped directory, Word, or PDF document containing answers to the above questions and images.