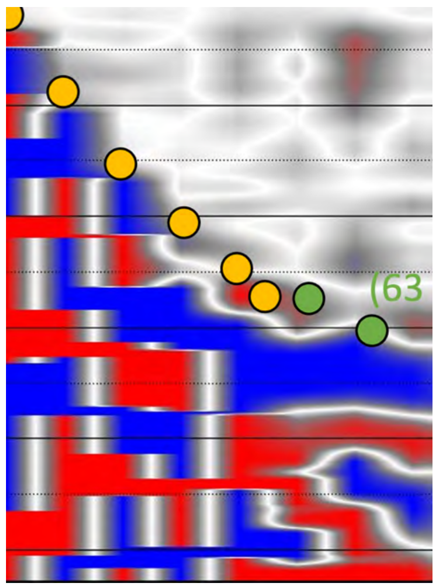
Instructor Workshop:

Teaching Near-surface Geophysics to Undergraduates from Intro to Majors

Workshop Materials for Participants



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EarthScope Consortium

QuickStart Guide for the Emlid Reach RS2/2+/3

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Quick Start

Emlid provides many good resources for getting started with Reach GPS/GNSS receivers https://docs.emlid.com/reachrs2/. This guide is designed to augment the online resources for easy access in the field.

Figure 1. Image of the Emlid Reach receiver. (1) power button, (2) battery status LEDs, (3) WiFi status, (4) RTK status

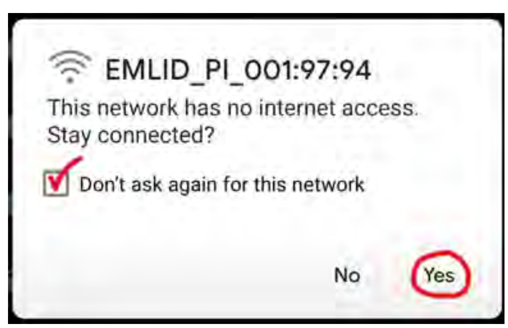
This QuickStart Guide assumes:

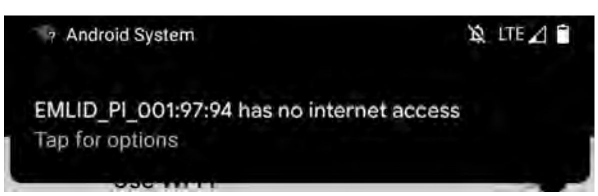
- Students have learned the basic overview of how Real-time Kinematic (RTK) GPS/GNSS surveys work with both base station and rover/s.
- The supplied Emlid Reach base and rover are preconfigured and fully charged so that you may rapidly carryout an RTK survey.
- You are provided a benchmark for the base station with accurate known coordinates.
- You are provided a tripod for the Reach base and survey poles for the Reach rovers.
- Minimal solar activity—check NOAA website (https://www.swpc.noaa.gov/)
- You already downloaded the **Emlid Flow** app from your phone/tablet's app store. Apple and Android are both supported. Do this before you leave cellular or WiFi range if you are headed to a remote field site. Also, while you are on cellular or WiFi, open a Survey project and zoom in on your field location so the maps download.

Turning on and connecting with a Emlid Reach receiver

1. Turn on the receiver by pushing the round button for 3 seconds until all LEDs light up. Wait until **WiFi status** light turns steady white (about 60 seconds). **White** shows that the receiver is in hotspot mode and broadcasting WiFi.
   (If the WiFi status light stays **blue** it means the receiver has joined a local WiFi network instead. You can join the same WiFi network and continue with Step 3 below. If you want the receiver to switch to Hotspot mode instead, see troubleshooting section below.)
2. Go to your phone/tablet's Settings and select the WiFi network broadcasting from the receiver you want to connect to (it will take a little while to show up after the receiver turns on).
   Password for all Emlid Reach is "emlidreach"

NOTE: After selecting the receiver's network on your list of available WiFi connections, make sure you are truly connected. On some Android and Apple phones, a pop-up notification may say that the newly selected network "has no internet connection" and will default to immediately disconnect unless you specify otherwise. See images below. The name of your receiver's connection may not be the same as shown below.

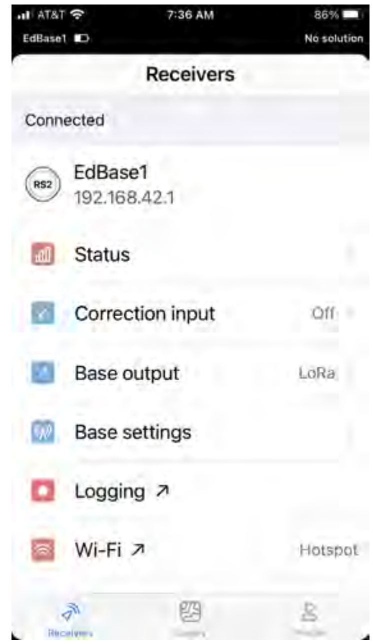


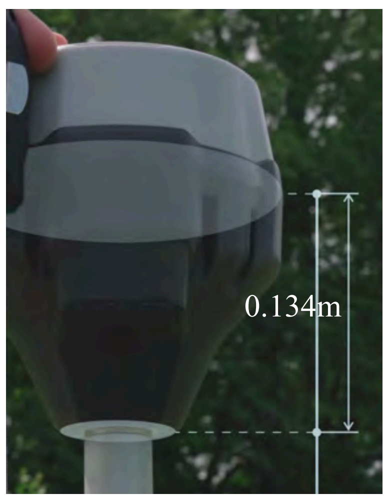


3. Open Emlid Flow app. If it is already open, it might work best to close and reopen. (Generally, if you have any issues with the Emlid Flow app, restarting usually helps.) Once the dot-lights on the receiver become solidly on, the receiver will show up in the Emlid Flow app and you can select it. This will take you to the Receivers page and show you the one you are connected to.

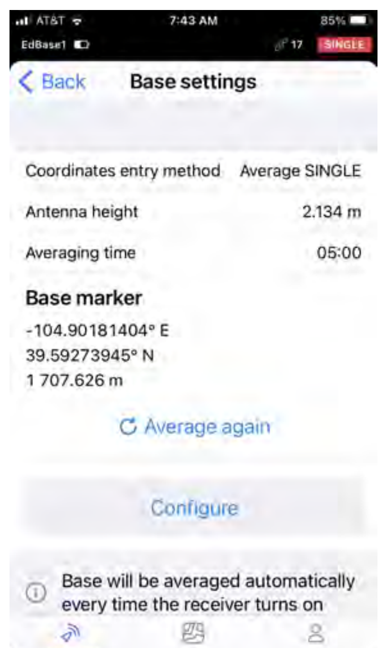
Starting the base

1. Attach the LoRa antenna and mount the Emlid Reach base on the tripod and accurately level over the benchmark.
2. Turn on and connect with the receiver as described above.
3. Select **Base settings**.
4. **Configure** > **Coordinate entry method** > **Manual** and enter in the coordinates for the base station that you have been given. **Antenna Height**: Measure from the ground to the base of the Reach device to determine the **Measured height**. For example, if you are using a 2-meter pole and quick-tripod setup, your **Measured height** will be 2 meters. The actual phase center of the antenna is 0.134 m higher but the receiver will include that automatically.





5. OR if the survey you are doing does not require a highly accurate base location and there is no known benchmark, your instructor might tell you to just collect a quick location. To do this, select **Average single** instead of **Manual**. Then select a duration of time to average the position over. Five minutes can work if your instructor does not tell you otherwise.
6. Select **Status** on the main receiver page and check that there are plenty of <u>Satellites in view</u>. Technically 4 is enough but these receivers are set to require 7 or more; more than 10 is best, and these days >15 is common. <u>PDOP</u> (position dilution of precision) describes the error caused by the relative position of the GPS/GNSS satellites. Basically, you want the satellites as spread-out across the sky as possible and not only in one area, say

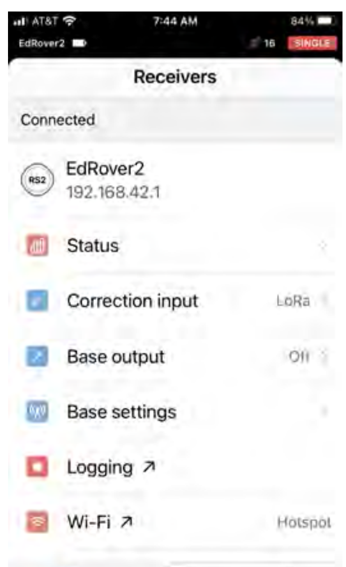


overhead. Low PDOP values, in the range of 4.0 or less, indicate good satellite geometry, whereas a PDOP greater than 7.0 indicates that satellite geometry is weak. Solution will be **Single** because the base is not receiving any corrections from another receiver. Estimated accuracy will likely be in the meter-range for the base.

7. Check **Logging** tab. Start recording Raw data (RINEX 3.03) and Position (LLH or XYZ). If the data are already recording, it means the previous user did not stop the logging before turning off the receiver, so the logging automatically restarted when the receiver was turned back on. This is ok, but less recommended. If you turned on the base station after the receiver was in place on the tripod, you can just let the logging continue. If the base station receiver was moving around while on, then you should stop the logging and then restart it. This will ensure that all the data in the file was collected after the receiver was in place. (Base correction should be off for the base station because it is not receiving corrections.)
8. When the survey time is complete, stop the Logging and export the Raw and Position files before turning off the receiver (see final step in Rover section below on how to export).

Starting the Rover

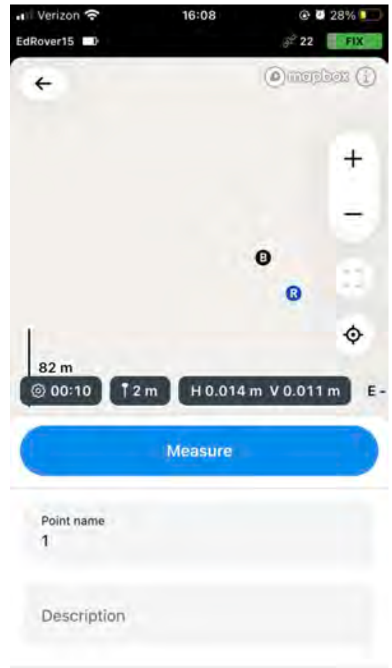
1. Attach the LoRa antenna and mount the Reach a survey pole. Turn on and connect with the receiver as described above in the base section. Select **Status** on the main receiver page and check that there are plenty of Satellites in view. Technically 4 is enough but these receivers are set to require 7 or more; more than 10 is best, and these days >15 is common. PDOP (position dilution of precision) describes the error caused by the relative position of the GPS/GNSS satellites. Basically, you want the satellites as spread out across the sky as possible and not only in one area, say overhead. Low PDOP values, in the range of 4.0 or less, indicate good satellite geometry, whereas a PDOP greater than 7.0 indicates that satellite geometry is weak. After a few minutes, the Solution should change from **Single** (no base correction) or **Float** (base connection but not full correction) to **Fix**, meaning all ambiguities are resolved and RTK solution is showing centimeter-level Estimated accuracy. Establishment of **Fix** is accompanied by a beep from the receiver. You are now ready to start your surveying. You can close the **Status** page.

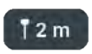


2. Check **Logging** tab. Start recording Raw data (RINEX 3.03), Position (LLH or XYZ), and Base correction (RTCM3). If the data are already recording, it means the previous user did not stop the logging before turning off the receiver, so

the logging automatically restarted when the receiver was turned back on. This is okay, but less recommended.

3. Go to the **Survey** icon on the bottom of them main receiver page. This feature allows you to make project-based point collection with auto-save rules or manually and then export the data into different formats. It is perfect for surveying and ground control point collection.
4. Click the + in the upper right corner to start a new project (or click on a project name to open an existing one). Give the new project a name, put down the people involved in the survey as Authors, and add a description if it will be helpful.



    a. Coordinate system
        i. Default is <u>geographic coordinates</u> which will appear as **Global CS** (which is the Emlid term for WGS 84, EPSG:4326) with vertical datum of "ellipsoidal height."
        ii. If <u>projected coordinates</u> are preferable, use **WGS84 / UTM zone xxx** (select correct zone for you region),
    b. Then click **Save**.
5. Press  to go to the point collection window. Open the pole height menu.  In most cases you will be using a 2-meter pole so no changes will be needed, but if your pole is a different height, enter that value instead. Click **Save**.
6. If you want the data collection to average over a certain time period, select  to choose the duration you want. <u>Ten seconds can work</u> fine if your instructor does not give you another protocol. To ensure highest quality results, it is a good idea to activate **FIX only** option. You will not be able to collect a point unless the rover has a **Fix** solution.
7. If you wish to change the point's name or add a description you can edit those in this menu. If you do not change it, the default point name will increment through "1," "2," etc. If you choose a name such as 'Point 1' the name will similarly increment automatically as you collect more points.
8. When you are ready to collect a point and the pole is being carefully held over the survey point with the level bubble leveled, select the blue "measure" button to start collecting.
9. If you are having trouble maintaining **Fix**, there are suggestions in the Troubleshooting section below. If that still does not solve the issue, your instructor may decide to switch to a PPK workflow. In that case, turn <u>off</u> **FIX** only and each collection point should be done for <u>30 seconds</u>.

10. Point options: To open the list of all points, press . You can open point details, edit the point info, find it on the map, or stake out the point. You can work with each point separately by choosing it on the map. Read more about Point Stake Out function (finding a point of known coordinates) in the Emlid guide (https://docs.emlid.com/emlid-flow/survey-with-ef/points/stakeout/). When you are done, press **<Projects** to close and save. The project will be available in the **Survey** menu.
11. Exporting Data: When you finish collecting points, you can export your project. Press ••• and **Export**. Generally, the default format is CSV. You will be prompted to decide how you wish to send the file. Then go to the Logging tab and turn off logging for Raw, Position, and Base

correction data and export those as well. *If you choose to email files to yourself and you are currently connected to the receiver hotspot, after you "send" the email, disconnect from the receiver hotspot so that the email can actually can go out via cellular or another WiFi network.*

Troubleshooting and some good things to know

This is not a comprehensive troubleshooting guide but addresses some of the more common issues.

1. If the Emlid Flow app does not seem to be finding the receiver or is taking a really long time to move from the selection pane to showing you the status of the receiver, try restarting the app. Restarting the app seems to help with many things.
2. If the WiFi LED light to the left of the power button is showing blue, then the receiver is joined to a local WiFi network rather than serving as hotspot itself. Join the same local WiFi network so you can connect to the receiver through it. Go to **WiFi**, then Activate the Hotspot. If you wish to prevent this in the future, you can "forget" the known WiFi network.
3. Some phones are set to not connect to hotspots/WiFi networks that are not connected to the internet. If you appear to be joined to the receiver's hotspot but are then not actually able to connect in the app, open your phone's settings. Select the receiver's WiFi network and require it to "join anyway" (even though it is not connected to the internet)
4. If the Emlid Flow app is saying "sorry Emlid Flow is not responding" try forgetting the receiver's WiFi network and then rejoining it again. Rebooting your phone/tablet can also work.
5. Survey maps not showing up – The maps need to be downloaded while you are on cellular or WiFi. If they are not showing up and you are already in the field, hopefully you still have some cell service. Disconnect from the Emlid and allow the app a chance to download the maps over cellular by zoom in on the field area while in your Survey project. Restarting the app can also help before you try to reconnect with the Emlid. If you are already out of cell range, the data points you collect will still be fine, the survey map view will just be less helpful.
6. The reference frame used by Emlids is WGS84 and vertical datum "ellipsoidal height".
7. Getting **Fix** status with the rover: Usually the rover shows **Fix** after a few minutes (accompanied by a beep). However, sometimes, it can take longer—even more than 10 minutes—for reasons that can be hard to determine. Here are some things to check:
    a. Make sure the LoRa antenna on both the base and rover are screwed all the way on. You often need to gently hold the little rubber flap back with one hand in order to get a completely perpendicular angle to screw in the antenna with the other hand.
    b. If your rover is still not getting a **Fix** status, trying waiting longer. If it still does not work, try restarting the rover. Moving to a slightly different distance from the base can help sometimes (perhaps there is interference at a particular distance OR you are too close to trees or buildings).
    c. Make sure that your base has a fairly accurate known location. If the base location is off by >10 meters from its actual location, it can take longer to get and keep **Fix** with the rover. If the base location is off by 100 meters, it is unlikely **Fix** for the rover will be achieved. If you used a **Manual** location in **Base coordinates**, check that you entered it correctly. If you used an **Average single**, try collecting again for a longer period of time.

d. If the rover is receiving corrections (you can check this by going back to the main menu and choosing **Correction Input** where it will either say "Waiting for corrections" or "Receiving corrections") and is in the **Float** status but not **Fix**, try moving to an area with better sky view.

e. If you have an Emlid Reach RS**3** try turning off the tilt compensation if it is on. This is a useful feature in certain tight situations, but not needed for most geoscience use cases. It seems to make the rover more fussy about achieving **Fix**.

f. Check solar activity (NOAA Space Weather https://www.swpc.noaa.gov/). It can affect the signal from the satellites as they pass through the ionosphere. If either the base or the rover is not getting consistent "lock" on at least seven satellites, the rover will not get **Fix**.

g. Consider whether there could be radio interference in your area from other sources or a significant multipath reflector (nearby buildings, vehicles, or trees reflecting the GPS/GNSS signal along a path longer than the direct signal).

h. If you lose **Fix** after having it, try coming back closer to the base. You may have lost line-of-sight between the two receivers and need to reestablish **Fix** from a closer point. You may need to experiment for a particular location on conditions for how far away you are able to get away from the base or what LoRa settings (above) are optimum.

i. Make sure you have the same LoRa settings in the *Correction output* tab on the base unit and in *Correction Input* on the rover. The base should be at full Output power of 20 dBm. You could also try adjusting the LoRa settings, such as lowering the air data rate (this typically allows the LoRa signal to have a longer baseline, although fewer corrections will be sent per unit time, so you would likely need to select just the GPS constellation to limit the amount of data). You could also try adjusting the frequency. Although generally higher frequency will penetrate further, you may have local interference at certain frequencies. Try stepping down 1–2 MHz at a time (of course you need to make the same changes on both base and rover/s).

j. If you still have trouble establishing **Fix** and would like to discuss it with a technician, please take multiple pictures of the site and contact education@earthscope.org.

k. In the meantime, if a survey needs to be completed that day, it may make sense to switch to a PPK (post-processing kinematic) survey. That workflow is described in the *Instructor Guide for Emlid Reach RS2/2+/3* (https://serc.carleton.edu/getsi/teaching_materials/high-precision/equipment.html#emlid). Be sure to increase survey point collection time to at least 30 seconds and hold that pole as still as possible even for this longer time.

Instructor Guide for Emlid Reach RS2/2+/3

Beth Pratt-Sitaula, Sam Beane, Diana Krupnik (EarthScope) and Brigid Lynch (Indiana University)

This document provides a guide on the setup of Emlid Reach RS2 (also RS2+/3) receivers and other functions that may be needed by instructors or field engineers. This manual includes:

1. *Updating receiver firmware*
2. *Initial settings for both the base and rover receivers for RTK survey*
3. *Good Base locations*
4. *Determining a known point for Base Position with Precise Point Positioning (PPP)*
5. *Base shift (moving the base during a survey)*
6. *PPK – Post processing kinematic*
7. *Using NTRIP over cellular to access a permanent GNSS station instead of a local base*
8. *Downloading a system report*
9. *Connecting to receiver using Windows or Mac computer browser*

1. Updating receiver firmware

*If you borrow equipment from the GETSI Field Project (EarthScope Consortium) you will most likely **NOT** need to do the steps in Section 1). The receivers should arrive to you with updated firmware and base/rover setting. However, these are provided for your reference or in case an update is released while the survey kit is in your possession.*

Figure 1. Image of the Emlid Reach RS2 receiver. (1) power button, (2) battery status, (3) WiFi status (4) RTK status. Steady white WiFi status means receiver is in Hotspot mode. Blue it is connected to a local WiFi network.

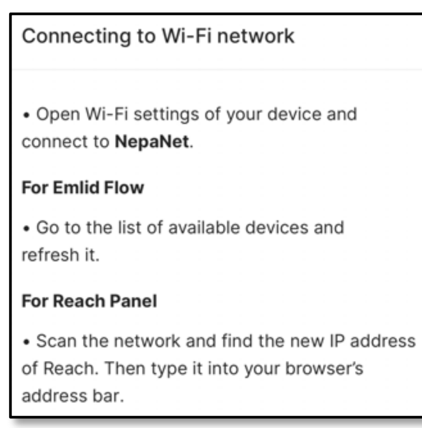
Charge receivers to full power

Check battery status of the receivers. Press the power button once to display the current power level (Fig. 1). If device needs to be charged, plug it in using the included USB charger.

Update firmware using phone or tablet

You will need the Emlid Reach receivers, a 2.4 GHz WiFi connection, and a smartphone or tablet with the Emlid Flow companion app installed (alternatively you can connect to the receiver using a computer as described in the last section below). If you have issues with the app, restarting it will typically solve the problem. For additional help with firmware updates: https://docs.emlid.com/reachrs2/reference/troubleshooting/updater/

1. Connect to the receiver as described in the Emlid Quick Guide with your phone/tablet using the Emlid Flow app (the receiver in hotspot mode and you are connecting to its WiFi network).
2. Next you need to change the configuration so that both the devices are on a **2.4 GHz** (not 5 GHz) internet-connected WiFi network, rather than having the receiver serve as a hotspot. **WiFi** > **Available**. Select the WiFi network that you wish to use. The receiver will then switch to that WiFi network and stop being a hotspot to your phone/tablet. You


Connecting to Wi-Fi network

• Open Wi-Fi settings of your device and connect to **NepaNet**.

For Emlid Flow

• Go to the list of available devices and refresh it.

For Reach Panel

• Scan the network and find the new IP address of Reach. Then type it into your browser's address bar.

will see a notice that says "Connection to Reach was lost." When both devices are on the same WiFi network, the phone/tablet can function again as a controller.

3. **Settings** (will have a red dot if a firmware update is available) > **New Reach Firmware is available** > **Update Reach** > **Update Reach**
4. It will take a few minutes for the update to download. It often helps to keep the phone screen active to maintain the connection between devices.
5. Backtrack through the app menus to get to the Receivers page. After a couple minutes, **Refresh** to find the receiver again. When the receiver is done turning on again, both the receiver and your phone/tablet will still be on the same local WiFi network. Select the receiver in the Emlid Flow app.
6. If you wish to have the receiver stop reverting back to the local WiFi network whenever it reboots, you can "forget" the local network. Go to **WiFi** > **Hotspot mode**. Turn the hotspot ON. Go to your phone/tablet's Settings and choose the receiver as your WiFi network again. Refresh or restart Emlid Flow app > choose the receiver. Go to WiFi page again and forget the local network that you had the receiver connected to.

2. Initial settings on base and rover for RTK survey

<u>*Base settings for RTK survey*</u>

This section provides a list of the initial settings that this receiver should arrive with from EarthScope if it is designated as the base. Starting from the initial ***Receiver*** *page once you are connected to the receiver (see Quick Guide for getting the app started).*

- **Correction input**: Off
- **Base output**:
  - Select **LoRa**
  - Frequency: 902.0 MHz
  - Output Power: 20 dBm
  - Air data rate: 9.11 kb/s
- **Base settings**
  - Configure > Coordinate entry method > Average Single
    - Note: the user may change this to Manual depending on their needs, but it will typically arrive set to Average Single (see more info below)
    - Average Single (to collect a quick location)
      - Coordinate Accumulation Time: options for up to 30 min but 5 minutes can work fine. It is fine to set it to "Average Single" if you are just collecting a longer occupation for PPP processing (see below PPP section).
    - Manual (If you are using a known benchmark location)
      - Antenna Height: Measure from the ground to the base of the Reach device to determine the **Measured height**. The actual phase center of the antenna is 0.134 m higher but the receiver will include that automatically. If you are using a 2-meter pole and quick tripod, this will be 2 m.
      - Enter in the Latitude, Longitude, and Ellipsoid height of the benchmark
  - RTCM3 messages:

i. ARP station coordinates: 0.1 Hz
ii. GPS MSM4: 1 Hz
iii. GLONASS MSM4: 1 Hz
iv. Uncheck Galileo MSM4, BeiDou MSM4, and GLONASS code-phase biases

- **Settings**
  - Base output 2: Off
  - Mobile data: Off
  - GNSS Settings
    - Elevation Mask Angle: 15°
    - SNR (Signal Noise Radio) Mask: 35°
    - If you are going to process a PPP survey in CSRS only select GPS and GLONASS. If you have other processing plans or if the base location is already known, then it may be fine to select GALILEO, QZSS, BEIDOU as well.
    - Update Rate: 1 Hz (How often the receiver recalculates its location; Emlid's recommended base setting is 1 Hz; 5 Hz also fine)
  - Position streaming 1: Off
  - Position streaming 2: Off
    - Unless you are connected to a real time permanent station for corrections.
- **Logging** – If the receiver was turned off with logging still going, it will automatically restart when you turn the receiver on. It is recommended to stop logging at the end of a survey and re-start manually for the next survey. This ensures that data files are ended and restart properly. So, it should be shipped with logging off.
  In general, the base will log **Raw data** and **Position**. The Base correction file is not relevant when a receiver is being used as the Base.
  Recorded logs and settings > **Gear Icon** > **Show Configuration** (if you want to see all the options):
  - Raw data:
    - Format: RINEX3.03
    - Either "CSRS" or "Custom" to start with (unless you specifically know a user wants to use OPUS)
    - Show configurations
      - Logging interval: 1 s
      - Satellite systems: GPS and GLONASS
    - Info for RINEX header: antenna height should be the same as in **Base settings** above.
    - "Automatically start recording" should be <u>unchecked</u>
  - Additional logs:
    - Position track: LLH (lat-lon-height); also fine to do X-Y-Z (coordinates from Earth's center), but that is less intuitive for most educational users
    - "Automatically start recording" should be <u>unchecked</u>
- **Status** – there are no settings on this page but it can be helpful to think about some of the info displayed
  - Satellites in view: just what is sounds like; 6 is really a minimum that you would want to use and more than 10 is better and these days more than 15 is very normal, although technically 4 is enough for a basic solution

  - PDOP (position dilution of precision): describes the error caused by the relative position of the GPS satellites. Basically, you want the satellites as spread out across the sky as possible and not only in one area – say overhead. Low PDOP values, in the range of 4.0 or less, indicate good satellite geometry, whereas a PDOP greater than 7.0 indicates that satellite geometry is weak. Aim for <2.0 if you can.
  - Solution: **Single**

Rover settings for RTK survey

*This section provides a list of the initial settings that this receiver should arrive with from EarthScope if it is designated as a rover. Starting from the initial **Receiver** page once you are connected to the receiver (see Quick Guide for getting the app started).*

- **Correction input**: should match the Base Output
  - Select **LoRa**
  - Frequency: 902.0 MHz
  - Air data rate: 9.11 kb/s
- **Base output 1**: Off
- **Base settings**: not relevant to a receiver set up as a rover
- **Settings** (scroll down to the ones lowest on the page)
  - Base output 2: Off
  - Mobile data: Off
  - GNSS Settings
    - i. Elevation Mask Angle: 15°
    - ii. SNR (Signal Noise Radio) Mask: 35°
    - iii. Generally, the base is only set to collect GPS and GLONASS because those are the systems that can be used with the CSRS PPP portal. The rover is also usually set to just be GPS and GLONASS but it is fine to select GALILEO, QZSS, BEIDOU as well if you wish.
    - iv. Update Rate: 5 Hz (Emlid's recommended rover setting)
  - Position streaming 1: Off
  - Position streaming 2: Off
- **Logging** - If the receiver was turned off with logging still going, it will automatically restart when you turn the receiver on. It is recommended to stop logging at the end of a survey and re-start manually for the next survey. This ensures that data files are ended properly. So, it should be shipped with logging off.
  In general, the rover should be logging **Raw data** and **Position** and **Base correction**.
  Recorded logs and settings > **Gear Icon** > **Show Configuration** (if you want to see all the options):
    - i. Format: RINEX3.03
  - Raw data:
    - i. Either "CSRS" or "Custom"
    - ii. Show configurations
      1. Logging interval: 1 s
      2. Satellite systems: GPS and GLONASS
    - iii. Info for RINEX header: antenna height should be the same as in Survey
    - iv. "Automatically start recording" should be <u>unchecked</u>
  - Additional logs:

i. Position track: LLH (lat-lon-height); also fine to do X-Y-Z (coordinates from Earth's center), but that is less intuitive for most educational users
ii. Base corrections: RTCM3

- Common settings:
  i. "Autostart" recording should be unchecked

- **Status** – same as above for the base except
  - Solution: Fixed (or Float) but fixed is needed for the full RTK solution

3. Good Base locations

When you choose a base location, you need to think about both the sky view for good satellite coverage, but also the base-rover communication. RTK surveys depend on a radio link between the base and rover. The goal is to have the base location and rover survey plan such that the rover is always able to achieve **Fix** between the devices. Some things to keep in mind:

- Open sky view, free from large nearby objects as much as possible (trees, buildings, etc.), and on stable ground. (see also the Kinematic GPS/GNSS Survey Methods Manual - https://serc.carleton.edu/details/files/108023.html; https://serc.carleton.edu/getsi/teaching_materials/high-precision/unit1.html - manuals)
- Line-of-sight between the base and rover is best for being able to do longer distances but over shorter distances may not be essential.
  - We have been able to get up to 8 km with full line-of-sight when base was on a building, the rover was used in various places that had a view of that building, and the air data rate was slowed from 9.11kb/s to 4.56 kb/s (this also meant only the GPS constellation was being used due to slower data transfer rate). Rover and base must have the same rate, so change them both if you are trying this adjustment. It is also recommended to turn off GLONAS. See Section 2 for making receiver settings changes.
- High ground for the base seems to particularly help.
  - We have been able to get ~5 km distance between the Emlid base and rover when the base was on a hill and the rover was out in the plains below. Line-of-sight largely available but not completely perfect.
  - Even without line-of-sight, having the base up on a hill allowed 1-1.5 km distance through trees and bamboo.
- Base placement can be a bit of an art. As an instructor, if you have time, you may choose to scope and test an ideal base location well before going out with students. That would also allow you to get the best solution using PPP (see next section). However, if you are not able to test the base location before going out with students, you can include the students in that part of the survey design and decision making, which is also a super valuable learning outcome, even if it reduces the time spent on addressing a geoscience research question.
- Troubleshooting suggestions for getting good **Fix** with the rover are given in the *Quick Guide*.
- If you still have troubles establishing **Fix** and would like to discuss it with a technician, please take multiple pictures of the site and contact education@earthscope.org.

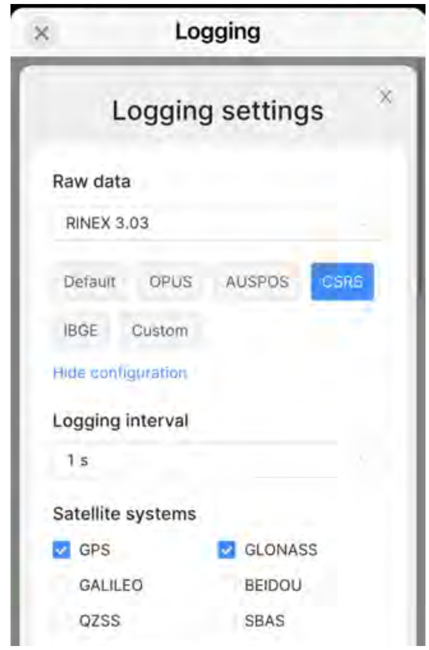
4. Determining a known point for Base Position with Precise Point Positioning (PPP)

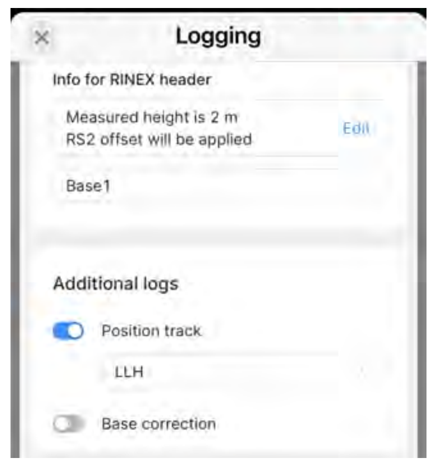
If you will be working at a location that does not have a known benchmark, you will typically want to get a known point for your base station. This section will describe setting up the base receiver for PPP and uploading the results to the Natural Resources Canada (NRCAN) Canadian Spatial Reference System website (CSRS-PPP) https://webapp.geod.nrcan.gc.ca/geod/tools-outils/ppp.php?locale=en. *It is* *ideal to do this workflow the day before, several days, or even two weeks before you want the known point for an RTK survey. If you prefer to use the NOAA's OPUS (Online Positioning User Service), Emlid describes that workflow https://docs.emlid.com/reachrs3/base-setup/determining-base-position/online-post-processing-services/opus-workflow/.*

The longer you collect the base location data ahead of time, the better the PPP solution because the satellite locations and correction are better known. There are three options:

- Ultra Rapid solution is available 1.5 hours after the GPS data are collected
- Rapid solution is available the next day
- Final solution is available ~2 weeks later when final satellite location data is included

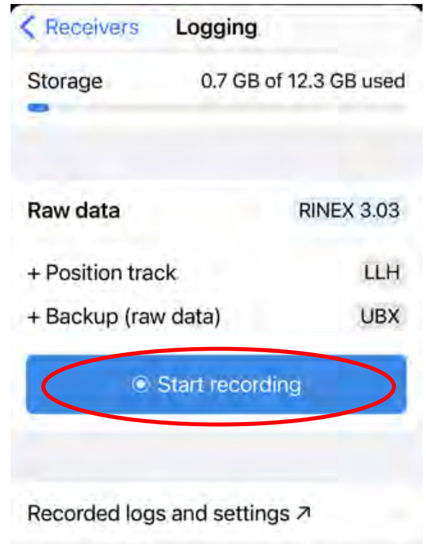
Read more about it (https://docs.emlid.com/reachrs/tutorials/post-processing-workflow/nrcan-workflow/). The Emlid Community Forum also has a nice example from someone who compared Ultra Rapid and Rapid deviations (https://community.emlid.com/t/study-of-deviation-of-ppp-with-rs2-with-different-observation-times/19185). The published accuracies suggest the Ultra Rapid will have decimeter-scale accuracy, Rapid will have ~½-decimeter accuracy, and Final will be ~2-cm accuracy. In practice we have often found only cm-scale differences between the three solutions. In some cases, Rapid and Final are essentially identical.



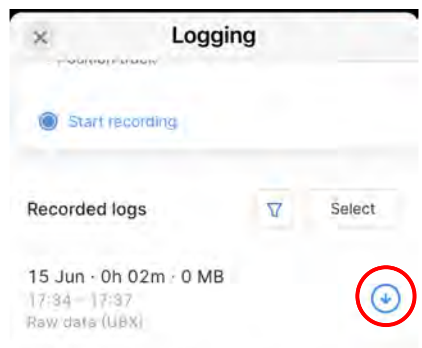


1. Set up the base tripod and receiver over the point for which you want to get a known position and turn the base receiver on.
2. Make sure the base is set up to collect data for the PPP service you plan to use (unless the base location is already a known point). Go to the Receiver page > **Logging** > **Recorded logs and settings** > **Gear Icon** > **Show Configuration** (if you want to see all the options). Select the PPP service you plan to use. This will probably be CSRS or OPUS. This will ensure that only the satellite systems that work with a particular service will be included.

3. **Format** > **RINEX 3.03** (unless you have a particular reason to use another format)
4. **Logging interval** > **30 s** is fine if you are <u>only</u> collecting base data at this time. If you are also collecting rover points for post-processing kinematic (see Section 6 PPK), then use **1 s** (as in GNSS settings).



5. It is fine to have "Backup source data for RINEX (UBX)" checked. Most people don't use it though.
6. **Measured height** is from the benchmark to the bottom of the receiver (in meters). This is 2-meters for a quick tripod and your measured value for a traditional tripod. You can also enter a Marker name. Click **Apply**. The measured height should be the same as in **Base settings.**
7. Back on the main **Logging** page, **Start recording** the Raw Data and Position. For more on logging within the Emlid Flow app: https://docs.emlid.com/emlid-flow/#logging
8. Allow the base receiver to collect data for at least 2 hours, preferably 4 hours.
9. Retrieve the raw data that was recorded:
   - In the **Logging** tab,
     i. Click the red "stop" button/s to end the logging
     ii. Scroll down lower on the screen; click on the download icon next to the data you want to download. (The data is organized by date, time and type.)

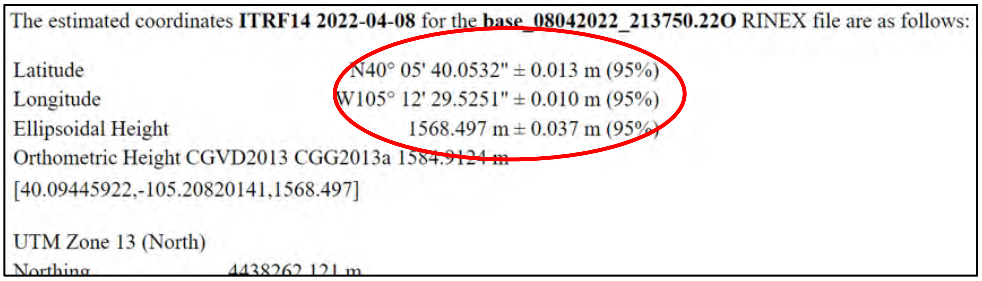


   - The data will download as a zip file onto your phone and provide methods to send it to your computer.
     i. Use any method (Airdrop, text message, email) to move the data from your phone to a computer.
     ii. You can either use the receiver's hotspot WiFi to do this or reconnect the receiver and your smartphone to your home WiFi.
   - You can also connect a laptop to the Emlid's WiFi hotspot or have both devices on the same local WiFi network. Then go to http://192.168.42.1/#logging in a browser window and downloading the files that way.
   - For more on downloading files from the Emlid Flow app: https://docs.emlid.com/reachrs2/tutorials/post-processing-workflow/nrcan-workflow#downloading-logs
   - Unzip the Raw data file and identify the observation file which will end .xxO (xx denotes the year as in .22O for 2022). It will also be the largest file by size.
10. Now you are ready to submit to CSRS: https://webapp.geod.nrcan.gc.ca/geod/tools-outils/ppp.php?locale=en
    - Create an account with them if you do not have one already.
    - Sign in to your CSRS account, enter the email that you would like the results sent to, then select *Static* and *ITRF*.

i. For more information on NAD83 vs ITRF and WGS84 see: https://www.e-education.psu.edu/geog862/node/1804#:~:text=It%20is%20important%20to%20note,plate%2C%20and%20moves%20with%20it

- Upload the .xxO file to CSRS.

11. Record the Latitude, Longitude, and height coordinate, found in the summary link of the CSRS email or in the pdf within the full_output_zip file. *Note: CSRS-PPP only retains saved files for 36 hours, so download them right away.*


The estimated coordinates **ITRF14 2022-04-08** for the **base_08042022_213750.22O** RINEX file are as follows:

Latitude	N40° 05' 40.0532" ± 0.013 m (95%)
Longitude	W105° 12' 29.5251" ± 0.010 m (95%)
Ellipsoidal Height	1568.497 m ± 0.037 m (95%)
Orthometric Height CGVD2013 CGG2013a	1584.9124 m

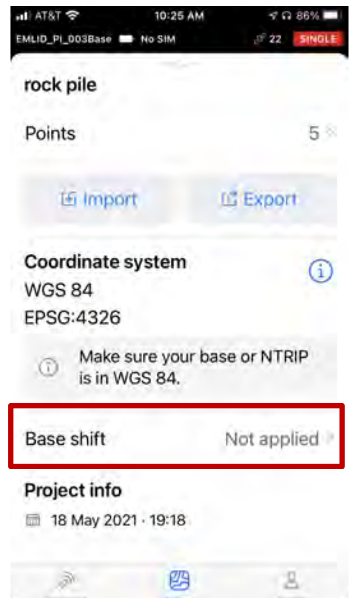
[40.09445922,-105.20820141,1568.497]

UTM Zone 13 (North)

Northing 4438262.121 m

5. Base shift *(moving the base during a survey)*

*There is a feature in the Emlids Flow app (Survey tab) called **Base shift** that will allow you to adjust the base position to a new location and carry on with the survey.*



This can be helpful if you want to move the base to a new location and keep going on the survey (ex. leapfrogging along a survey line that is too long to do from a single base position; you might move the base to the position of a point surveyed by the rover). It does **not** shift the location of the previously collected rover points.

1. Go to **Survey** and then select the **Project** for which you want to shift the base. Scroll down below the map to **Base shift**.
2. Measured point > +Add point > Select the existing survey point that you want to use for the new base position > Apply
   OR
3. Known point > +Add point > Fill in the longitude, latitude, and height. (For instance, this could be a PPP solution from CSRS [see above]).

6. PPK – Post processing kinematic

*Post processing kinematic (PPK) allows one to determine corrected rover positions after the survey is completed. The base and rover do not need to have a LoRa radio connection during the survey. This can be a good option if you are having trouble getting **Fix** between the base and rover, if you know ahead of time that line-of-sight will not be possible, or if you will not be able to acquire a known point for your base station prior to the kinematic survey day. Download Emlid Studio software.*

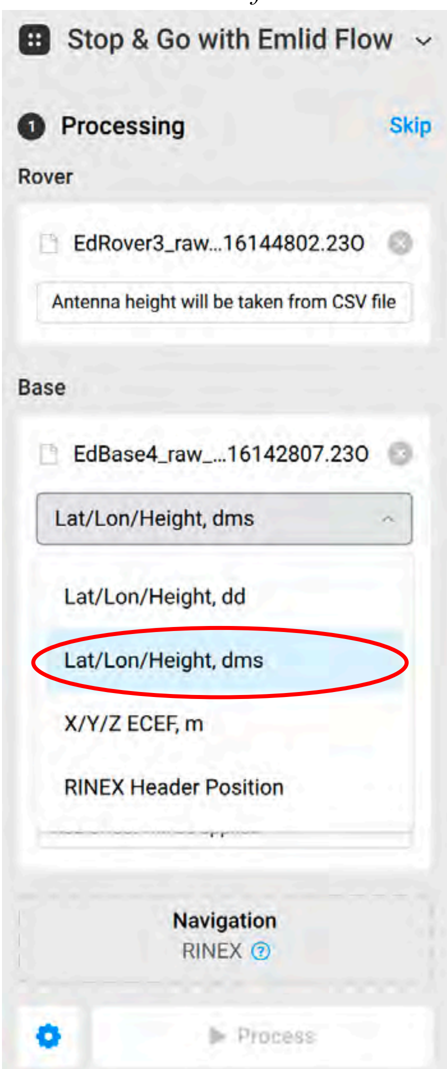
Preparing to collect data

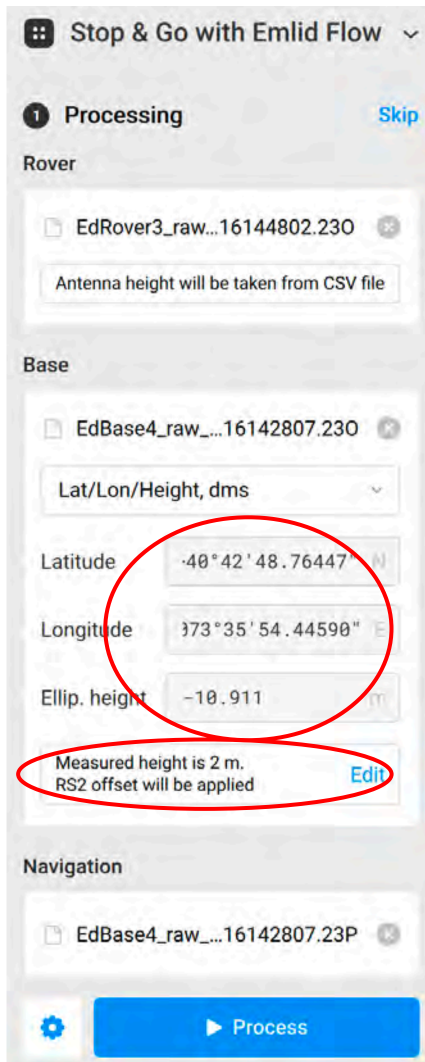
1. Follow the procedures in the PPP section above (Section 4) for details on base station set-up and data recording settings.
2. For both the base and the rover, go into the Receiver page > **Logging**.
   Make sure that raw data is being logged, if it is not, click on the blue circle to start recording.
   The data should be logged in RINEX 3.03 format.
3. Once the data logging is enabled, collect the survey data as you normally would, except make sure that you collect for at least 30 seconds at each rover point.
4. A base occupation of at least 2 but preferably 4 hours is best.

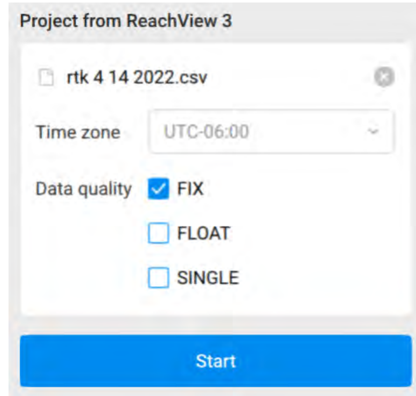
Post-processing

1. Download the RINEX files from both the base and the rover (see instructions in Section 4 PPP).
2. As usual, also download the .csv project file of rover points from the Survey page.

3. Submit the base station data to your PPP service of choice to an online processing service (see Section 4 PPP).
4. Open Emlid Studio. In the dropdown menu in the upper left corner, select **Stop & Go with Emlid Flow**.
5. Drag the RINEX .xxO file from the Rover into the Rover box.
   Note: the "xx" in the RINEX file's extension indicates the collection year. ".22O" means it was collected in 2022.
6. Drag the RINEX .xxO files from the Base into the Base box. Select **Lat/Lon/Height, dms** from the drop-down. Enter the base coordinates from the PPP service you used.
   Note: Emlid Studio will read the base height from the RINEX file but you can edit if needed in the Base section of Emlid Studio:







7. For the Navigation file, drag in the .xxP file from the base.
8. Click **Process**.
9. For the next step, **Generating Corrected CSV**, drag in the survey project you exported from the Emlid Flow app (.csv file). Select the data quality you would like to keep (Fix, Float, Single). If you are doing PPK because you did not have line-of-sight between base and rover during your survey, you will probably want to select Fix, Float, and Single.
10. Click **Start**.
11. The output files should be saved in the same folder on your computer as the input files came from but sometimes it ends up in another recent folder. The resulting csv file will have the same name as the original but with '_corrected' added to the end of the file name.

7. Using NTRIP over cellular to access corrections from a permanent GNSS station instead of a local base

This section will describe how to set up a rover receiver to NTRIP (Networked Transport of RTCM via Internet Protocol). NTRIP allows the rover to receive corrections over the internet and does not require a base receiver. You will need one Reach RS2+ or RS3 receiver that will be the rover station, two smartphones or tablets with the Emlid Flow companion app installed on one, the other will provide a cellular hot spot to the receiver. You can also use a SIM card (not provided) inserted into the receiver if you cannot use your smartphone as a cellular hotspot or do not have two smartphones.

You will also need access to an NTRIP provider in your region. One free option is the Network of the Americas (NOTA) real-time data service. This network has much higher density in the western US. Look for stations near you on the NOTA Real-time Network Monitoring Map. https://www.unavco.org/instrumentation/networks/status/nota/realtime. *Request access by emailing rtgps@unavco.org.*

Note: The longer the baseline between base (NTRIP station) and rover, the lower the resulting accuracy. Uncertainty increases by ~1 mm per km distance on top of the ~1 cm initial uncertainty. This means that an NTRIP station 30 km away will allow at best 4-cm accuracy. Baselines should be 50 km at most. Less than 20 km is better.

For more information on NTRIP see: https://www.unavco.org/data/gps-gnss/real-time/real-time.html and https://igs.bkg.bund.de/ntrip/ For Emlid notes on using NTRIP see: https://docs.emlid.com/reachrs2/quickstart/ntrip-workflow

The rover receiver needs an internet connection to work with NTRIP. There are two ways to connect the Reach to the internet:

1. Turn on mobile data on your smartphone and share it with the receiver over a WiFi hotspot, the reach will connect to your network and get internet access.
   - The smartphone used as a WiFi hotspot cannot be used to connect to the receiver through the Emlid Flow app. You will need a second smartphone or a SIM card to control the receiver.
2. An active SIM card in the receiver avoids the use of a smartphone hotspot.
   - You will need a Nano SIM card for the Reach,

- Insert the SIM card into black sealing at the bottom of the receiver.
    - Slide the metallic cover to the right, lift it up, insert the SIM card into the cover, close the cover and slide it to the left to lock it in place.

If you will be using two smartphones follow these steps:

1. Prepare your smartphone to provide a mobile hotspot.
    - Typically, you will find this under Settings/Cellular
2. Turn on your receiver and make sure it is in hotspot mode, WiFi symbol (Fig. 1) is white.
    - To turn hotspot mode on, select the menu in the upper right corner (Fig.1), select WiFi and switch **Hotspot** to On
3. On the smartphone you will use to control the rover, connect to the Rover via its WiFi hotspot.
4. Return to the rover's WiFi settings, and connect the rover to the phone's hotspot which should be listed under **Available Networks**.
5. In the **Correction Input** settings, select the *NTRIP* tab, and enter:
    - Address (the IP address of your provider)
    - Port (specified by your provider)
    - Username for your NTRIP provider
    - Password for your NTRIP provider
    - Select your **Mount Point** from the dropdown list.
        - This is your closest GPS station in the network. Scroll through the pull-down list to find the correct station. Be sure to select the closest location with the **RTCM3** option.
    - Format: RTCM3
6. Once these changes are applied and you are connected, the bottom of this page should show that you are *connected* in green text.
    - On the **Status** page:
        - Grey bars next to orange and green bars confirm that you are receiving a correction.
        - **Solution Status** should be **Fix** and the accuracy should be around 0.01m. If not, restart the controller/receiver.
7. At this point, you can leave the smartphone that is acting as the hotspot in your pocket and control the rover with the other smartphone to collect data. No need for a base!

If you are using a SIM card instead of a second smartphone follow these steps:

1. Turn on your receiver.
2. Open the Emlid Flow app on your smartphone, click on the rover device and wait for the SIM card to load (it will say *Loading…* at the top of the app).
3. If the SIM card is locked, you will be prompted to enter the PIN for the SIM card. Once connected you should see green bars under Status.
4. Go to the menu and select **Mobile Data** and switch to On. You should now see network bars at the top of the Emlid Flow app next to the battery icon.
5. In the **Correction Input** settings, select the *NTRIP* tab, and enter:
    - Address (the IP address of your provider)
    - Port (specified by your provider)
    - Username for your NTRIP provider
    - Password for your NTRIP provider
    - Select your **Mount Point** from the dropdown list.

  - This is your closest GPS station in the network. Scroll through the pull-down list to find the correct station. Be sure to select the closest location with the **RTCM3** option.
- Format: RTCM3
- Once these changes are applied and you are connected, the bottom of this page should show that you are 'connected' in green text.

6. On the **Status** page:
   - Grey bars next to orange and green bars confirm that you are receiving a correction.
7. **Solution Status** should be **Fix** and the accuracy should be around 0.01m. If not, restart the controller/receiver.
8. You are now ready to conduct your survey without a base.

8. Downloading a system report

This could be useful in order to retain record of the settings you used. It could also help if a field engineer is trying to diagnose any issue remotely.

1. Connect to the receiver WiFi and open the Emlid Flow app. Select the receiver, then select Emlid Flow.
2. **Settings** > **Troubleshooting** > **System report**.
3. Select the simple or full report.
4. Simple report > Copy. This will copy the report to the clipboard. Now this can be pasted and emailed as text.
5. Full report will generate a zipped file, this can be downloaded as well and then emailed or otherwise transferred but cannot be copied as text to the clipboard. The simple report does have most settings that we would need to troubleshoot the issue.

9. Connecting to receiver using Windows or Mac computer browser

One can also connect to the Emlid Reach receivers using a computer instead of a mobile device as described in the first section. Instead of using Emlid Flow, you can find all the same information and controls via a browser for both Mac and Windows machines.

Connecting computer to receiver over WiFi

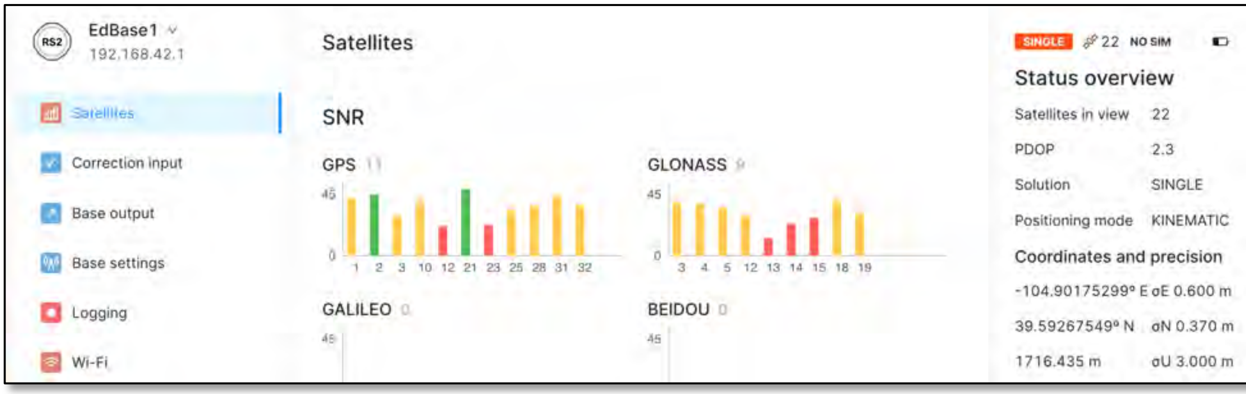
Note: Emlid Reach devices **require 2.4 GHz** (not 5GHz) WiFi network. If you intend to connect your receiver to a local network, determine that the network is at least dual frequency. Typically, Emlids will successfully connect to the 2.4 GHz component of a network with both 2.4 and 5 GHz.

To see the Emlid controls on your computer browser (or a browser on your phone), the main thing you need to know is the correct IP address to enter into the browser address bar.

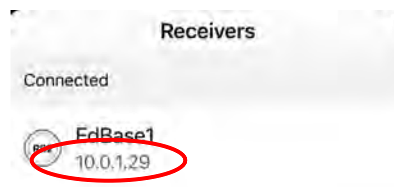
Make sure you are on the same WiFi network as the receiver.

1. **Hotspot mode** – if the receiver WiFi indicator light is **steady white**, the receiver is sending its own hotspot signal.
   a. Join the receiver's hotspot with your computer. On a Windows machine, you may need to select "Connect using a security key instead" (of a pin number). Then use the typical password: emlidreach.

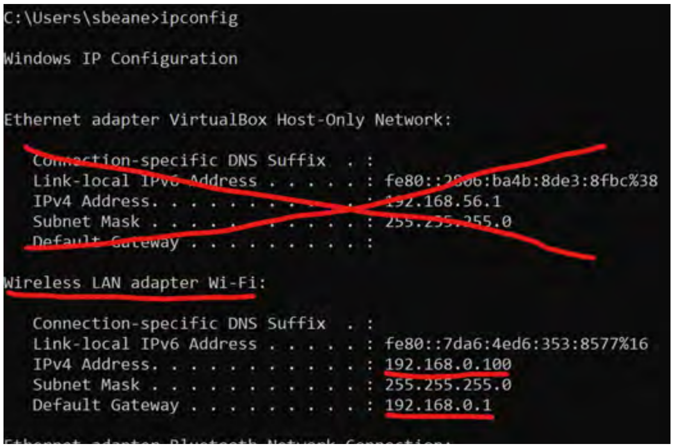
b. Open a browser window and enter IP address **192.168.42.1** into the browser address bar. You should see a page that looks similar to Emlid Flow but more spread out.



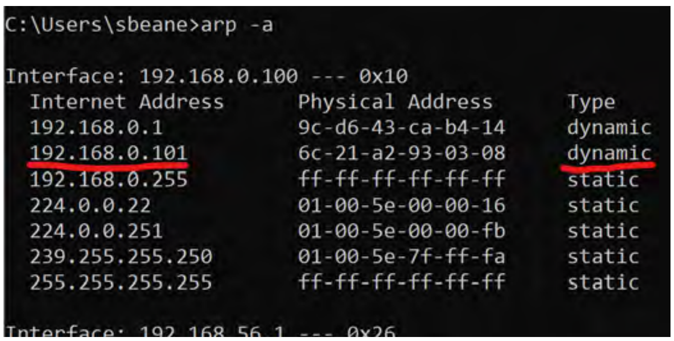
2. **WiFi network** – if the receiver WiFi indictor light is **steady blue**, the receiver is on a local WiFi network.
   a. Join the same WiFi network with your computer. Now you need to find out what IP address the receiver has on the local network.
   b. **Option 1**: Download a program called "Fing" (fing.com) to easily find the IP address of your receiver under "devices" and enter the specified IP address into your browser address bar.
   c. **Option 2**: If you also have a mobile device with Emlid Flow, you can find the IP address listed under the receiver's name in the app. Ex. 10.0.1.29. Then enter the specified IP address into your browser address bar.



   d. **Option 3 Windows**: Find the IP address of your receiver via command prompt.
      i. In the command prompt, enter "ipconfig".
      ii. The IP address of your computer is listed under WiFi next to "IPv4 Address".
      iii. Then, enter "arp -a" to provide a full list of devices on your network. The receiver will likely have an IP address very similar to that of your computer. It will also have a "dynamic" IP address and will be listed as so. (see screenshots below)



"ipconfig" showing the router's IP address as 192.168.0.1 and this computer's IP address as 192.168.0.100



"arp -a" showing the router and receiver IP addresses. If you have a lot of devices on the network, it may take a few tries to figure out exactly which one the receiver of interest.

iv. Enter this IP address into a web browser address bar.

e. **Option 3 Mac**: Find the IP address of your receiver via the Terminal by entering "arp -a" and entering that IP address into a web browser. Again, it may take a little trial and error to find which device on the network is the receiver of interest.

Connecting Mac computer to receiver using USB cable

1. Turn on the receiver and connect via USB cable (same one used for battery charging).
2. In System Settings > Network, you should see "ReachRS" pop-up with a green light and an IP address 192.168.2.XX. This is the IP address of your computer on this network.
3. Emlid sets an IP address for when the Emlid Reach is connected with a cable to be **192.168.2.15**. Enter this in a web browser.

Note: at the time of writing, the method to connect Windows machine using Ethernet over USB was complicated and not reliable.

Electrical Resistivity Tomography Survey Preparation—Additional Supplies, Planning, Safety, and Field Note Recommendations

This document is intended to augment other guides specifically about the data collection and analysis and help people newer to electrical resistivity tomography be ready for the field.

Additional supplies

EarthScope Primary Instrument Center (EPIC) does not typically provide all the supporting supplies that are needed or recommended for an electrical resistivity tomography (ERT) survey because needs vary and because some are prohibitively heavy to ship repeatedly. However, EarthScope may be able to help low-resource institutions purchase the supplies the first time. Contact education@earthscope.org if this would reduce use barriers for your course.

- 1-2 100-meter measuring tapes
- A tarp on which to place the SuperSting, switch box, and batteries if you are working in a dusty or damp setting. This will make it easier to keep the connectors clean. Suggestion: lay out the tarp and put the equipment on the downwind side. That way if wind comes up or it starts to rain you can quickly fold the upwind half of the tarp over the equipment. (Even more luxurious is a camp chair and even a folding table. Even if you do not put it underneath, have a tarp available in case of rain.
- Extra mallets or hammers: At least one should be included with the ERT equipment, but to make deployment faster, you can bring extra so more than one person can be setting stakes at the same time.
- 5–6 camping stakes per 100 m tape to hold the survey tapes in the ground. Use stakes to hold both ends, and if there is topography, you may want to hold intermediate points to the ground as well. Be careful about the stake at the far end of the line—you don't want to pull the survey tape off the spool. You can put a couple of wraps of the survey tape around a stake at the far end of the line, if you don't leave the tape in that position for too long. Any folding from the wraps should come out as you rewind the tape. Rewind the survey tapes carefully before you move any tape to a new location, a tangled tape or one that does a 180-degree twist can cost a lot of time to fix.
- One or two 12-V deep cycle marine batteries and 12-V battery charger OR a generator with a floating ground and fuel for it.
- An umbrella for sun, if it is sunny and not too windy. It can be hard to see the tablet and computer screens in full sun.
- Work gloves are recommended for anyone deploying and setting up equipment.
- High visibility vests are recommended, especially in urban or busy areas.
- Flags, caution tape, or signs: Since there is a rick of electrocution if someone touches the system while it is one, it is recommended that if you are in an area where people uninvolved in the survey may come across it that you mark out or block off the line and spread students out along the line to look out for people or even animals.
- Water or salt water, clay, aluminum foil: to increase soil conductivity, you can either spray the surrounding soil around the stakes with water or salt water, put clay inside the holes with the stakes, or wrap the stakes in aluminum foil before placing them in the

ground. (don't spray salt water unless it is permissible in your field site; i.e. probably not on a campus quad)

- Optional: If you are doing a long survey you may want walkie-talkie radios so that students all along the line can be alerted when the equipment is on and so they can quickly alert the person running the survey if there is an issue.

Site Selection

- Choose a site where there is room to lay out a line with length ~5 times the depth you want to image. See below "electrode spacing" instructions to compute exact length.
- Gently undulating surface topography or topography with a uniform dip will be more straightforward to interpret.
- You need a surface with some soil to push the electrodes into. Solid rock is impossible and loose sand will give very noisy data. A grassy field is great.
- The line location can be close to development but consider if any infrastructure will cause interference. Is the site near power lines, underground utilities, metal fences, etc.?
    - Ideally run your line perpendicular to these obstructions and place your first electrode at least one electrode spacing away.
    - If you need to run parallel, set up at least 15% of the line distance away.
    - With power lines, for safety remain at least 50 meters away.
- You will want a space halfway down the line with room to set out the equipment and battery.

Before data acquisition

- Research what you might expect in the subsurface at your site. What types of rocks or soils and their possible depths, the location of the water table, any possible underground infrastructure. If the expected depth of a feature you want to find is fairlydeep, then plan a longer survey line. Decide which type of array geometry might work best based on what you know of the structure and the particulars of each array geometry.
- Look through Unit 3 of the ERT module to help you plan the survey.
    - The introduction to electrical imaging video/power point goes over how ERT surveys are done and discusses the different types of arrays.
    - The Scenario Evaluator for Electrical Resistivity (SEER) Excel tool can help you test out possible designs but letting you input your initial predictions of the subsurface model and see how different arrays and spacing affect the resulting model.
- Choose an electrode spacing. Assume that the survey will "see" to a depth around ¼ to 1/5 of the total line length. SuperSting R8, it will come with 56 electrodes – so choose a simple spacing between electrodes, such as 1, 2, 3, 4, or 5 meters. For example, to image to 20 m depth, your line should be 100 m long. An electrode spacing of 2 m will give you a line length = (55 intervals * 2m interval) = 110 m. Note the SuperSting R8 resistivity cables come with spacings of 2 m or 5 m, you can't collect with spacings larger

than the cable spacing. If 2 m spacing is sufficient, request the 2m cables as they are lighter to ship and easier to manage.

- Print out the resistivity electrode positions table to help students properly place and locate individual electrodes. It's very useful for looking for electrodes with high contact resistances.
- Make a checklist of things you will take to the field and bring home from the field. (Sample checklist supplied.)
- The night before the survey, charge the batteries and the tablet and laptop. Make sure you have enough fuel for the generator if you're using one.
- The day of the survey, check with a voltmeter that the battery is charged (>12.7 V).

During data acquisition

- Make sure every student is behaving safely, staying away from the electrodes and cables while the system is on.
- Students should make a sketch of the experiment in their field notebooks, carefully noting the locations of all electrodes. If you can, get GPS positions for all electrodes or at least the first and last electrodes of every line you do.
- Make sure students note the direction of any survey. For example, on a line that runs NW–SE, is the first electrode at the NW end or the SE end?
- Make sure students record the specifics of the survey: how many electrodes and their spacing and what array type are you using (Wenner, Dipole-Dipole, etc.), as well as any other pertinent information (like the max n and max dipole if doing dipole-dipole).
- Students should record the names of the data files and what lines, locations, or groups they correspond to.
- After you are finished, if the pounded-in stakes don't come out easily, hit them on the side to create a bigger hole to pull them out.
- Pull up stakes before you pull up the survey tape. (If working in tall grass, stakes alone may be hard to find.)
- Use the checklist again at the end of the day to make sure no equipment is left in the field.

Date:
Start time:
Group number and names:

Equipment Check Out Log ERT			
	Load	**Load field**	**Comment**
ERT Equipment Boxes			
56 stakes			
hammer or mallet			
4 electrode take out cables			
Male-to-male jumper cable			
SuperSting			
Switch box			
Switch box and SuperSting connector cable			
WiFi antenna			
2 battery cables (use with battery)			
2 AGI power supplies (use with generator)			
tablet (fully charged)			
laptop (fully charged)			

Two 12V batteries (fully charged)			
wood or plastic to place under batteries			
generator and fuel			
car tablet charger (optional, but recommended)			
car laptop charger (optional, but recommended)			

should have at least one of the three:

water / salt water (spray dispenser recommended)			
bentonite clay			
aluminum foil			

1-2 100-m tape measures			
stakes/flagging			
tarp (optional)			
umbrella (to shade screen from sun/rain)			
handheld GPS (or phone GPS)			
work gloves			
high vizability vests (optional)			

Resistivity Electrode Locations

2 m spacing		3 m spacing		4 m spacing		5 m spacing	
Electrode	Loc	Electrode	Loc	Electrode	Loc	Electrode	Loc
1	0	1	0	1	0	1	0
2	2	2	3	2	4	2	5
3	4	3	6	3	8	3	10
4	6	4	9	4	12	4	15
5	8	5	12	5	16	5	20
6	10	6	15	6	20	6	25
7	12	7	18	7	24	7	30
8	14	8	21	8	28	8	35
9	16	9	24	9	32	9	40
10	18	10	27	10	36	10	45
11	20	11	30	11	40	11	50
12	22	12	33	12	44	12	55
13	24	13	36	13	48	13	60
14	26	14	39	14	52	14	65
15	28	15	42	15	56	15	70
16	30	16	45	16	60	16	75
17	32	17	48	17	64	17	80
18	34	18	51	18	68	18	85
19	36	19	54	19	72	19	90
20	38	20	57	20	76	20	95
21	40	21	60	21	80	21	100
22	42	22	63	22	84	22	105
23	44	23	66	23	88	23	110
24	46	24	69	24	92	24	115
25	48	25	72	25	96	25	120
26	50	26	75	26	100	26	125
27	52	27	78	27	104	27	130
28	54	28	81	28	108	28	135
tarp & SuperS		tarp & SuperS		tarp & SuperS		tarp & SuperS	
29	56	29	84	29	112	29	140
30	58	30	87	30	116	30	145
31	60	31	90	31	120	31	150
32	62	32	93	32	124	32	155
33	64	33	96	33	128	33	160
34	66	34	99	34	132	34	165
35	68	35	102	35	136	35	170
36	70	36	105	36	140	36	175
37	72	37	108	37	144	37	180
38	74	38	111	38	148	38	185
39	76	39	114	39	152	39	190
40	78	40	117	40	156	40	195
41	80	41	120	41	160	41	200
42	82	42	123	42	164	42	205
43	84	43	126	43	168	43	210
44	86	44	129	44	172	44	215
45	88	45	132	45	176	45	220
46	90	46	135	46	180	46	225
47	92	47	138	47	184	47	230
48	94	48	141	48	188	48	235
49	96	49	144	49	192	49	240
50	98	50	147	50	196	50	245
51	100	51	150	51	200	51	250
52	102	52	153	52	204	52	255
53	104	53	156	53	208	53	260
54	106	54	159	54	212	54	265
55	108	55	162	55	216	55	270
56	110	56	165	56	220	56	275

SuperStingR8 ERT Quick-Start Guide

Danielle Kinkel (EarthScope Consortium)

Pre Setup

Ideally scope out potential field sites ahead of time to know conditions and survey line placement. If there is an obstacle blocking you from deploying the full line, either shift the line over or restrict the number of electrodes you use. You want to try and make the electrode line as straight as you can.

Fully charge the batteries, and any other needed equipment such as the tablet and/or computer. We recommend bringing along a portable charger for the tablet or computer, since the battery can quickly drain if you need to have the screen brightness at max in order to see it outside. A sunshade umbrella is useful to help make the tablet and the SuperSting screen easier to see in the bright sun.

You will need a command file to run your survey, defining the type and layout. There are four command files preloaded on the SuperSting, a Wenner and a Dipole-Dipole layout for 28-electrode and 56-electrode lines. The names are: “dd28fr” “dd56fr” “wn28fr” and “wn56fr”. If you wish to create your own command file, this can be done ahead of time on a laptop or tablet and then uploaded to the SuperSting. See the Appendix for instructions on how to create command files.

Safety

Always treat the system as ON whenever it is connected to a power source. Do not touch any of the electrodes or cables and maintain a few feet of distance whenever possible and avoid stepping on the cable when the battery is disconnected as well. Do not deploy a line if there is a chance of lightning. If a storm begins after you have started, immediately move away from the equipment and get to a safe location.

If you are in a public space where people may come across your equipment, it is a good idea to mark out a boundary with flags, caution tape, or signs to help prevent someone from unknowingly stepping on or touching the setup. Watch for people and spread researchers along the line, if necessary, especially if there is not clear visibility along the whole length.

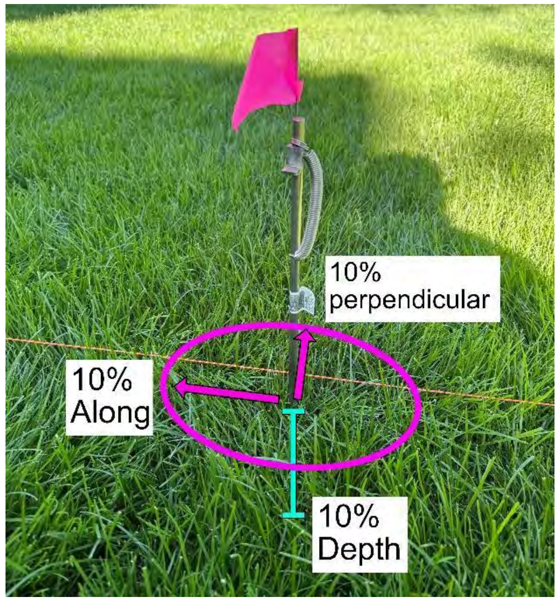
Work gloves and high visibility vests are always recommended for field work.

Equipment Setup

1. Lay out the measuring tape, doing your best to keep the line straight. Have someone step on the end of the measuring tape or stake it to the ground to keep the end in place.

2. Begin placing the stakes at your desired spacing, using a mallet to hammer them in.

    a. The stakes should be hammered into the ground at no more than 10% of the electrode spacing length; so, if the electrode spacing is 1 meter, the stakes should not be more than 10 centimeters deep. Sometimes you may need to move the stakes due to obstructions in the ground like rocks. The stakes shouldn’t deviate from their designated location by more than 10% of the electrode spacing and ideally move the stake perpendicular to the line rather than along the line.



b. Stakes should be fairly vertical, although perfect verticality is not necessary. It is also helpful to place the stakes all facing the same way, towards the side of the line where you plan to leave the excess cable coils, if any.

c. If the soil is particularly hard, you can use a power drill with a standard twist bit, with a similar or smaller diameter to the stakes, to help you create a pilot hole that you can then finish hammering the stake into. You still won't be able to go through rocks or concrete, so you will still have to move the stake location if you encounter them.

3. One of the most common issues is to have poor soil contact with the electrodes, particularly if the soil is dry. This can be remedied by spraying the electrodes with water or salt water, using bentonite clay around them, or wrapping the electrode stakes in aluminum foil.

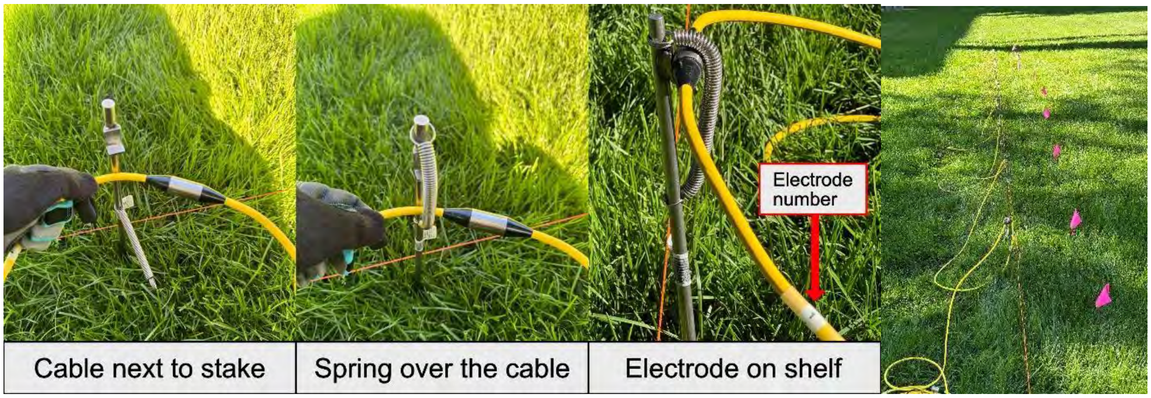
4. Place the takeout cable next to the electrodes. **<u>Do not drag the cable on the ground</u>**, carry it and place the electrode takeout contacts next to the stakes.

   a. The cable is labeled with the electrode numbers. Make sure the cables are connected in order, so the 1-14 cable connects to 15-28, and the 29-42 to the 43-56 cable, and the Switch Box and SuperSting are connected in between electrodes 28 and 29 for a survey with >28 electrodes.
      i. If you are doing a <u>28-electrode survey</u>, put the Switch Box and SuperSting before electrode 1.

   b. To connect the cables (14-to-15 and 42-to-43), connect the female end of one to the male end of the other. Line up the notches and push them together. Twist until they click into place.

   c. Also, for this cable and every other cable and port, try to avoid getting dirt in the connections. Leave the caps on until you are ready to connect and avoid placing uncapped connections on the ground.

5. Connect the stakes to the cable. Take the spring off the stake, loop it over the cable and reconnect, adjust the cable so that the silver electrode takeout is touching the stake and on the shelf of the stake. Coil all excess cable neatly on one side of the line.



Cable next to stake | Spring over the cable | Electrode on shelf

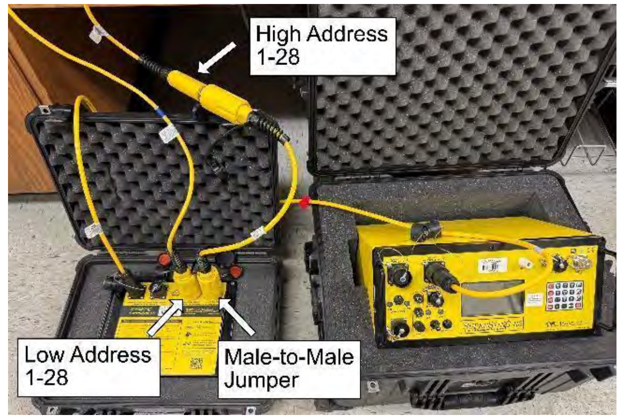
6. Connect the Switch Box and the SuperSting. Ideally you want to connect to the labeled female port on the Switch Box, so connect the female end of the cable to the SuperSting, and then the male end to the Switch Box.

7. Connecting the takeout cables to the Switch Box.

    a. Electrodes 1-28 are the low addresses, 28-56 are the high addresses, make sure to connect the cables to the correctly labeled ports.

    b. The low address cable can connect directly to the Switch Box.

c. You will need to use the male-to-male jumper cable to connect the high addresses.



1. Connect the WiFi antenna to the SuperSting. Twist into the WiFi port and tilt the antenna so it is pointing up.

8. If using a battery:

   a. Connect the barrel end of the battery cable to the SuperSting.

   b. Connect the additional battery cable to the first if using a second battery.

   c. Connect the alligator clips to the batteries. Red to positive and black to negative.

   d. Batteries should be placed on plastic or wood to prevent them from creating a ground loop with the electrodes. The outdoor example photo uses a storage tub lid.


9. If using a generator

    a. Connect the two AGI power supplies to the SuperSting.

    b. Start generator, then plug in the power supplies.

    c. The generator should have a floating ground (i.e. no grounding wire).

Operating the Survey

You can operate the survey on the SuperSting with its built-in screen, or through a connected tablet. The menu layout on the SuperSting is the same as the tablet, so the photos and steps line up with whichever method you use.

1. Turn on the SuperSting with the power switch, the lights and menu should come on.

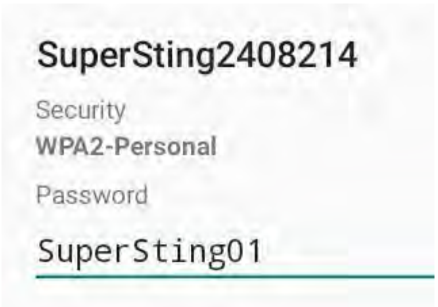
2. Make sure the communication switch is set to WiFi, the red light will be on.

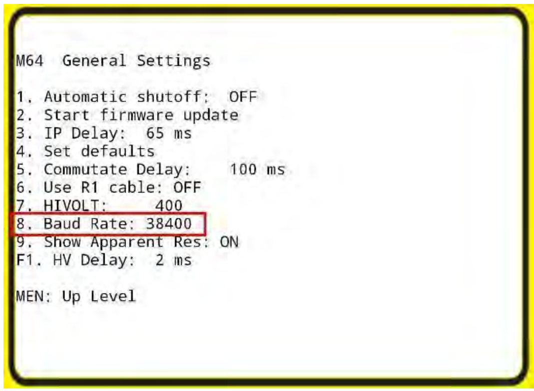
3. To connect the tablet, go into the WiFi settings, connect to the one labeled SuperSting[serial number].

    a. The password is **<u>SuperSting01</u>**

    b. Since the SuperSting WiFi doesn't connect to the internet, the tablet may ask if you want to stay connected, select Yes.

    c. If it is not connecting, check the SuperSting is using the correct baud rate by using the numpad and menu on the SuperSting, going into "6. system settings", then "4. general settings", and check that "8. Baud Rate is 38400". You can also have any device not connected to the SuperSting turn off their WiFi.



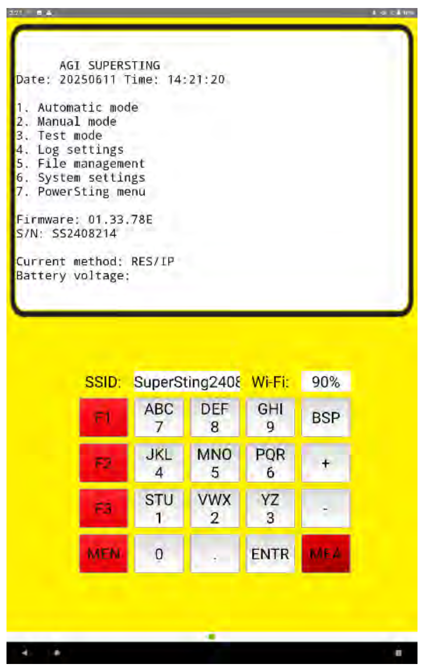


4. Open the AGI SuperSting Manager app. If you are connected, it will say "SS Connected: Yes" at the top and all the tabs on the main menu will be working.

5. Use the Transfer Data tab to upload your command file if you are not using one of the ones provided or have not already done so with one you made yourself (see Appendix).

6. Open the “Remote Control” tab to take control of the SuperSting and begin your survey.

    a. You will need to use the number pad to make your selections, e.g, pressing 6 opens System Settings.



7. Select “1: Automatic mode”

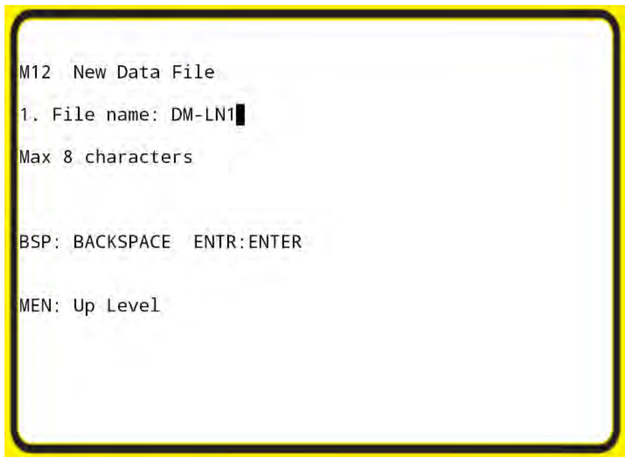
8. Select “2: Create data file”

9. You should be on the “New Data File” screen and asked to create a file name.

    a. You have a maximum of 8 characters to create the name. Numbers are typed by pressing their labeled button. To type a letter, you use the F# and number buttons. The F# corresponds to the letters position on its number button. So, the letter A is F1 button, then 7 button, because A is the first letter on the 7 button. The letter R is F3 then 6 because it is the third letter on the 6 button.

b. Name the files systematically. If you have multiple locations you're surveying, you could use "location name abbreviation-line #", ex: "VAL-LN1". If different groups are using the device, then we suggest "GR1-LN1" format. Different days, "month day -LN#".

c. Press "Enter" to continue once you're done.



10. Next you need to select the command file, the instructions to the SuperSting on how to do the survey. You can select one of the preloaded files ("dd28fr" "dd56fr" "wn28fr" "wn56fr"), or you can use one you created (see Appendix). Press "Enter" when done.

11. On the "Data File Setup" screen you need to add the information specific to your survey.

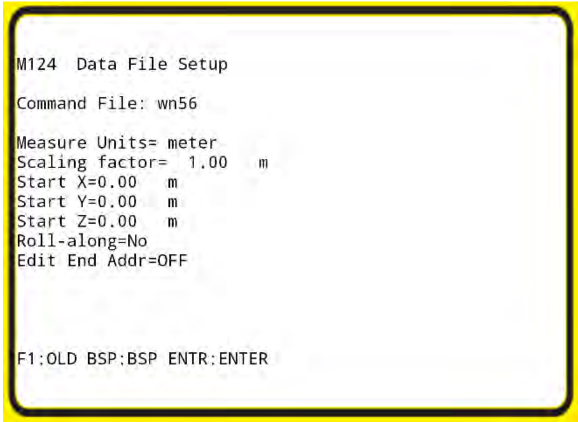
    a. "Scaling factor" is the distance between the electrodes. Make sure the units are set correctly.

    b. The "Start" options are for entering the starting coordinates of the line. It is not necessary to fill those out, so you can leave them as a default of 0.

    c. Select Yes for "Roll-along" if you are doing a roll-along study, which is where after you finish first measurements, you take one section of cable and electrodes and leap-frog them to the other side of the other cable, advancing the line when your desired line is longer than the electrode cables. (this is less common for starting users)

    d. "Edit End Addr" lets you specify the last electrode if you cannot use all the electrodes for some reason -- such as an obstruction preventing you from deploying all of them. You enter the number of the last electrode to be used.

    e. Press "Enter" when done.

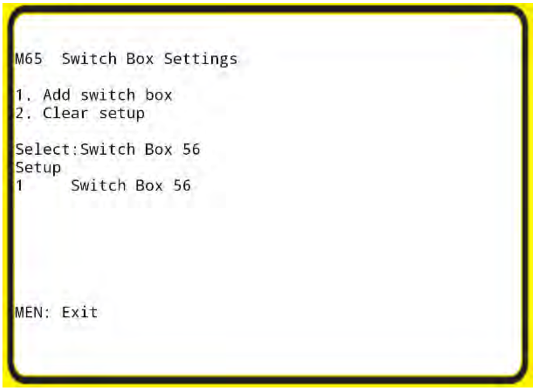


12. You should arrive back to the “Automatic Mode” menu.

    a. If you entered anything incorrectly, you can fix it by selecting “3: Edit survey information”

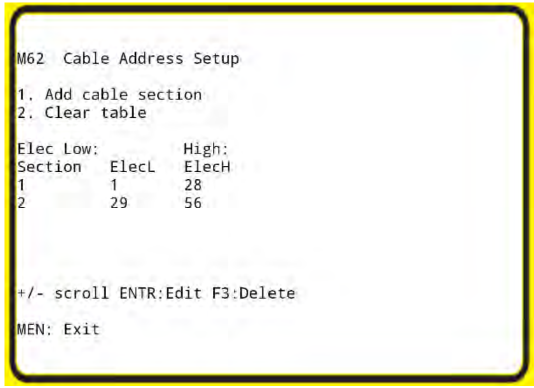
    b. If everything is correct, press the “MEA” button to continue.

13. Select “1. Switch Box”. Select “Add switch box”. Press the “+” key until you see “Switch box 56”. Press “ENTR”, then press “MEN” to exit.

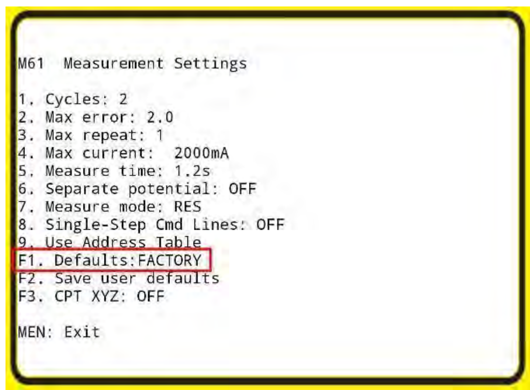


14. On the “Cable Address Setup” screen you need to specify which electrode numbers go with each cable section.

    a. Press “1. Add cable section”. For section 1, the low addresses, you will set “Elec Low” as 1 and “Elec High” as 28. Repeat these steps for the high addresses section, setting “Elec Low” as 29 and “Elec High” as 56. Press “MEN” when done.



15. On the “Measurement Settings” menu, it is recommended you use the factory defaults. Press F1 to change the setting if it is not correct. Press “MEN” to exit.



16. The “Contact Resistance Test” is to make sure your electrodes have good contact with the soil.

    a. Set your “Start address” to 1 and the “End address” to 56, or if you are doing a shortened survey, set the “End address” to the last electrode you are using.

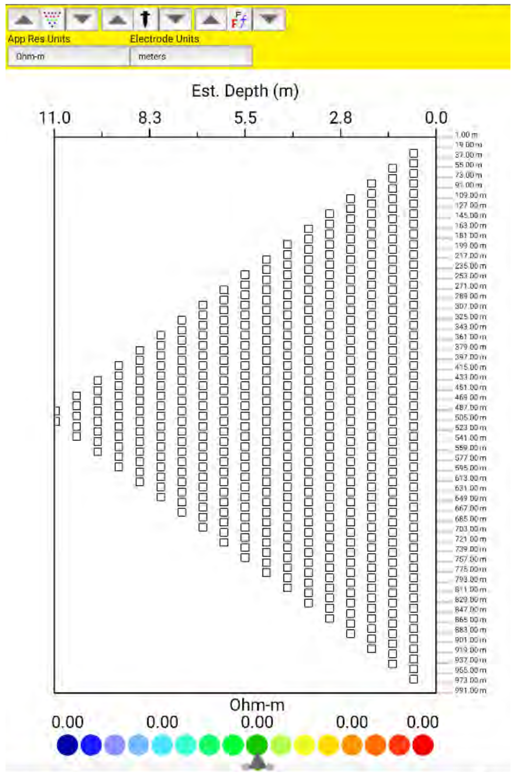
    b. Press F1 to start the test.

    c. Great contact resistance is anything <1,800 ohms, but acceptable up to 5,000 ohms

    d. If you receive an error, most likely the electrodes have poor contact with the soil, which can be helped by spraying it with water or salt water, adding bentonite clay around the stake, or wrapping aluminum foil around the stake. Also look out for any stakes that are not connected correctly to the cable.

    e. If you need to touch an electrode, turn off the system and disconnect the batteries before proceeding. **Anytime you need to touch cables or electrodes, disconnect the batteries to remove the risk of electrocution**.

17. Once you are back at the “Automatic Mode” menu, check that all the information is correct and then press “MEA” to begin collecting data. The tablet will switch to showing you a real time pseudo section once the measurements have started.



Packing up the setup

1. Turn off the SuperSting, wait for the lights to go off, and then fully disconnect the batteries before doing anything else.

2. We suggest you take the stakes out and then the cable since they are easier to lose in vegetation. Remove the spring, remove cable, reconnect spring. **Make sure to clean all electrodes, you want to remove any soil and corrosives, like salt. The stakes should be fully dry before putting them back in the case.**

3. **Do not drag the cable along the ground**.

4. **Carefully coil the cable** -- do over-under coiling such as with a climbing rope. **Don't wrap it around your arm like an extension cord**.

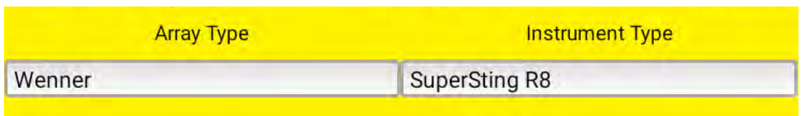
5. Make sure the caps are placed back on the cables and all the ports on the Switch Box and SuperSting.

Appendix: Creating Command Files

Command files tell the SuperSting what array type you are using and the specifics of how you want it done. These can be created on the tablet, ideally before going into the field. Examples are shown for Wenner and Dipole-Dipole array types. If you wish to use another array type, refer to the full manual for the information needed. Roll-along surveys use the same command files as regular surveys. There are four files preloaded for you, “dd28fr” “dd56fr” “wn28fr” and “wn56fr”, for standard Wenner and Dipole-Dipole arrays using 28 or 56 electrodes. Choose different names for your files or you won’t be able to upload them. Whatever command files you use, keep good notes about the details of your array set up.

1. Open the “Command Creator” option on the tablet app.

2. Start by selecting the “Array Type” and the “Instrument Type”, which should be set to SuperSting R8.



3. For a Wenner array:

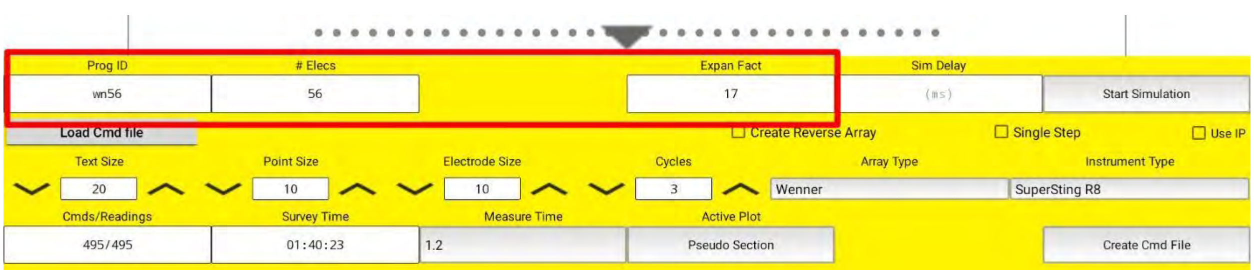
    a. Fill out the boxes highlighted in red. The other fields are not necessary; they are for display purposes.

    b. “Prog ID”: The name of the file. The recommended format is “[array type][number of electrodes]”. Ex: :wn56fr” for a Wenner array using 56 electrodes and running through both forward and reverse (reciprocal).

        i. Add additional details to the name to match specific characteristics of the array or if there is a command file that already exists with the name. Ex: If you decide to change the expansion factor to 20, name the file “wn20-56”.

    c. “# Elecs”: The number of electrodes you will be using.

    d. “Expan Fact”: The expansion factor. Should be ≥ 0.3 times the total number of electrodes in order to sample all possible data points. E.g., for a 56-electrode array, it needs to be at least 17.



4. For a Dipole-Dipole array:

a. Fill out the boxes highlighted in red.

b. “Prog ID” and “# Elecs” same as above.

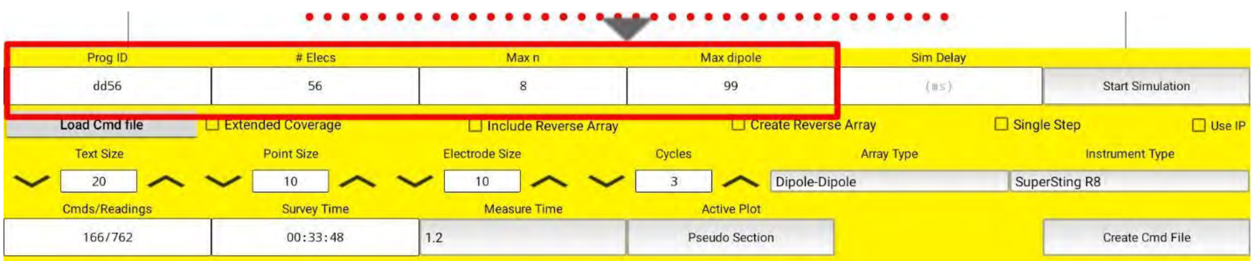
c. “Max n”: The distance between the transmitter and receiver dipoles, in units of electrode spacing. 8 is typically a strong enough signal for most surveys.

   i. If your spacing is 1 meter, your max n is (8 x 1) = 8 meters

d. “Max Dipole”: Controls the depths you sample. Should be at least 10% the total number of electrodes if you want to sample the deepest depth.

   i. If you want to ensure you get all the data, set an arbitrarily large number.

   ii. If you only want to sample shallow depths, use a smaller number.



e. Check the box for “Include Reverse Array”

   i. This will create the reverse (reciprocal) measurements and double the number of measurements. Note the image for step 4 shows “Cmds/Readings 166/762” and the image that includes reciprocals reads “Cmds/Readings 332/1524.”

   ii. By convention, the Prog ID for this new array is “dd56fr,” where dd is for array type (dipole-dipole), 56 is the number of electrodes, and fr means that forward and reverse (reciprocal) measurements are included in the command file.

f. Notes:

   i. This image shows the parameters for the “dd56fr” command file.

   ii. Including reciprocals for a Wenner array is not as straight forward. However, a dipole-dipole array is the best array to use for teaching due to its speed.

   iii. The other parameters in the image are slightly different to reduce the survey time. “Cycles” is reduced to 2, so each measurement is measured twice. “Measure Time” is reduced to 0.2, so current is injected for 0.2s for each cycle of each measurement.

5. Once you have entered your parameters, select “Start Simulation”.
    a. This will create a pseudo section showing you the expected depths it will sample, click on the grey arrow to see the whole thing.
    b. This also displays the number of command lines and the time it will take to run the survey in the bottom left corner in the “Cmds/Readings” and “Survey Time” boxes.
6. If everything looks correct and meets your needs, select “Create Cmd File”.
7. To upload the command file to the SuperSting, go back to the app’s main menu and select “Transfer Data”, then select “Upload Command Files”.

Resistivity Module Unit 4: Installing ResIPy

Ann Mariam Thomas (EarthScope Consortium)

Introduction

This guide provides instructions for installing ResIPy (Blanchy et al. 2020) on Windows (Section 1) and MacOS (Section 2) systems. Linux users can also install ResIPy by following the MacOS instructions and making a few adjustments. For Linux-specific deviations and troubleshooting tips, users will be prompted to ResIPy's GitLab page.

1. Installation for Windows Users

1. Navigate to ResIPy's GitLab page and scroll to the 'Downloads' section.

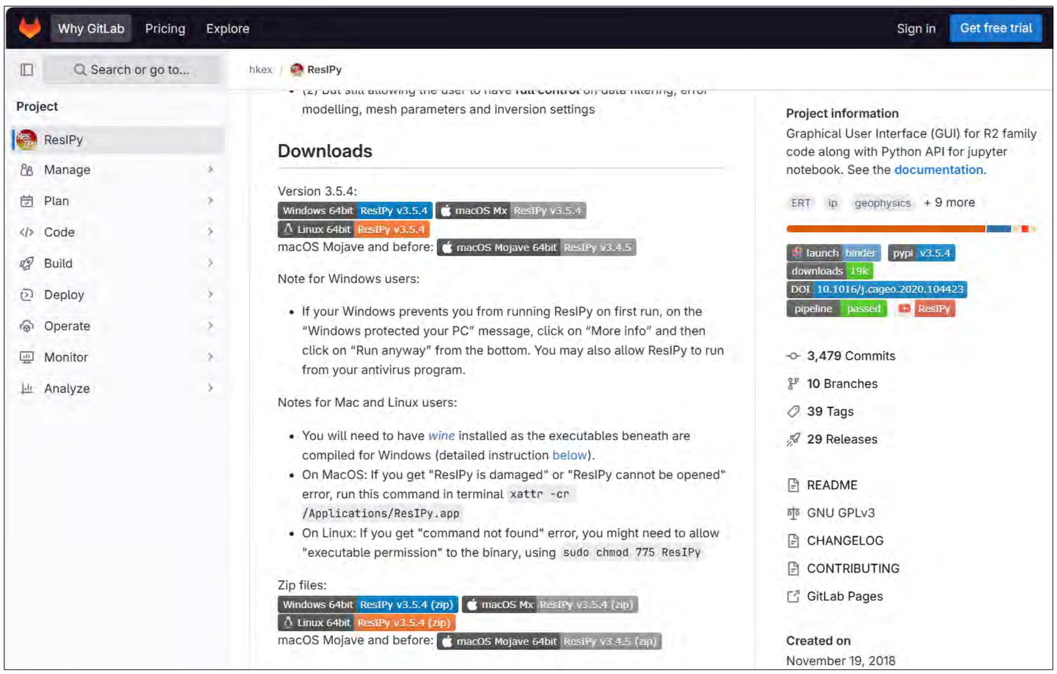


Figure 1. Downloads section of ResIPy's GitLab page

2. Double click the icon, directly underneath the 'Downloads' header, that matches your operating system. This will download a .exe file.

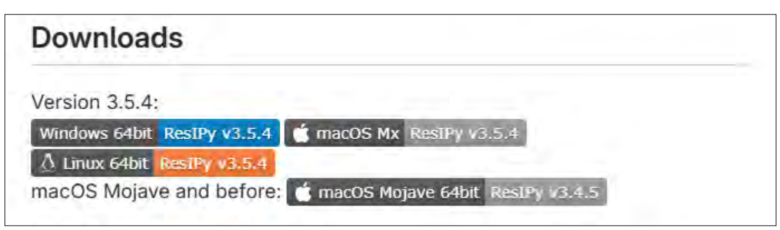
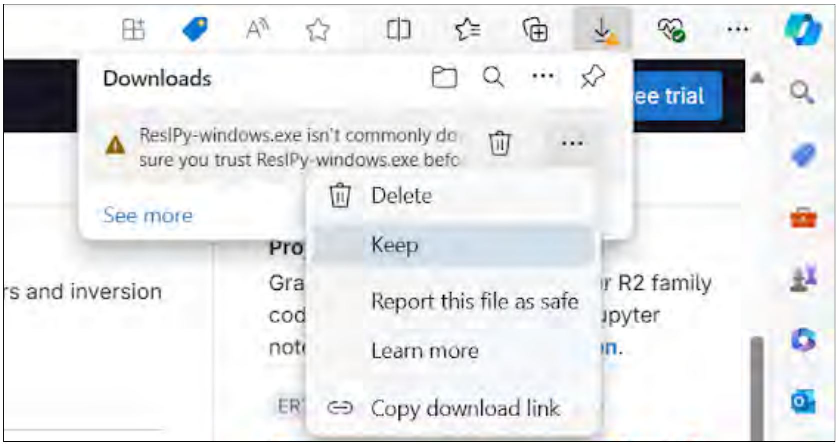


Figure 2. Download .exe file

NOTE: If Windows prevents this download and gives a security warning, click on the '...' icon next to the warning and select 'Keep'. If prompted with another message, click 'Show More' and select 'Keep anyway' to bypass the security warning.



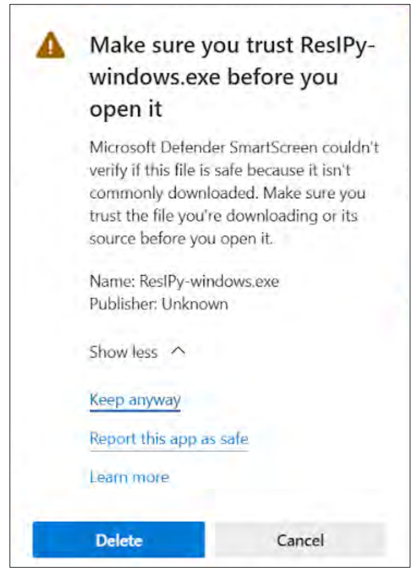


Figure 3. Bypass Windows security warning

3. Once your .exe file has finished downloading, double click the file. If you see a 'ResIPy' loading screen and the following window (Fig. 4), then you have successfully downloaded and installed ResIPy ☺

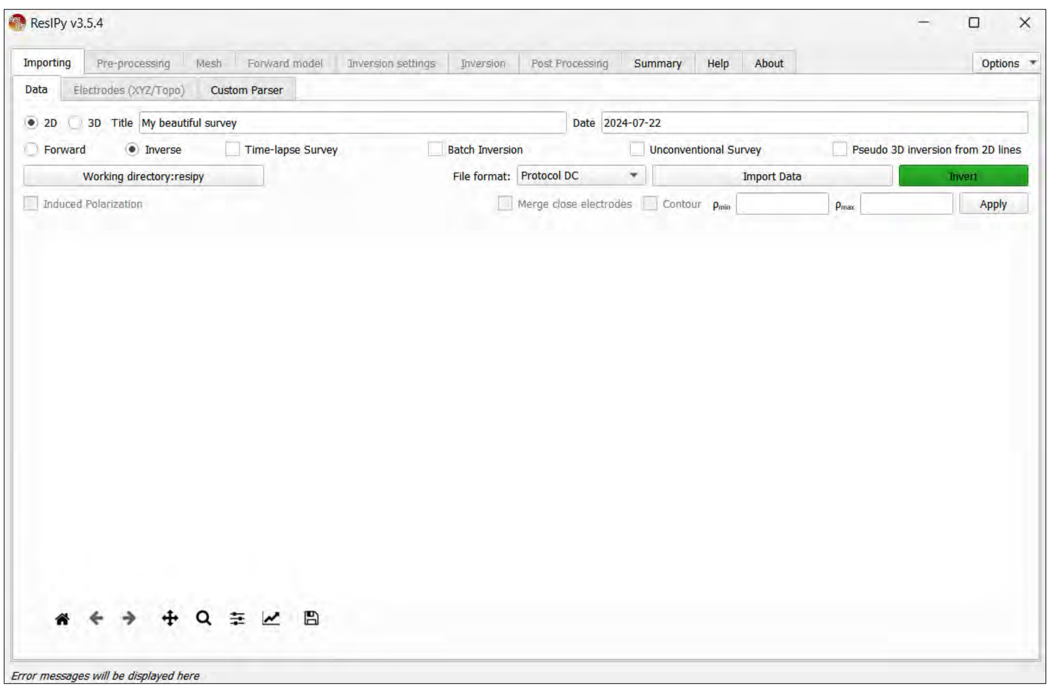


Figure 4. ResIPy window

2. Installation for MacOS users

1. ResIPy in MacOS systems requires the installation of Xquartz (an open-source version of the X.Org X Window System) and *Wine* (a compatibility layer used to run Windows applications). We will use Homebrew (a package manager) to install the two requirements. Linux users, use the instructions given in the ResIPy's GitLab page for *Wine* installation and skip to Step 4.

   To install Homebrew, open 'Terminal' on your machine and run the command (Fig 5.):
   /bin/bash -c "$(curl -fsSL https://raw.githubusercontent.com/Homebrew/install/master/install.sh)"

   Enter your administrator password when prompted in Terminal. (It can take up to a few minutes for each stage in the Terminal window to complete.)

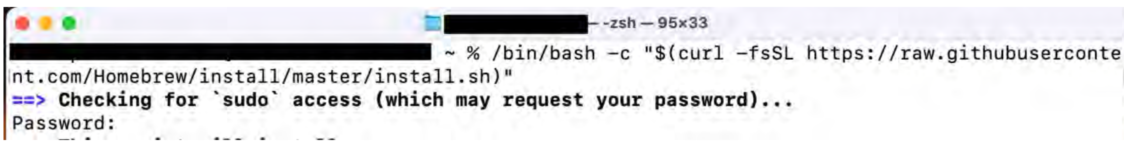
   

   Figure 5. Homebrew installation in Terminal

   If you see a **Warning** near the end of all the text in the terminal window that says "/opt/homebrew/bin is not in your PATH.", run the commands listed under "Next steps" in the terminal window. (Fig 6)

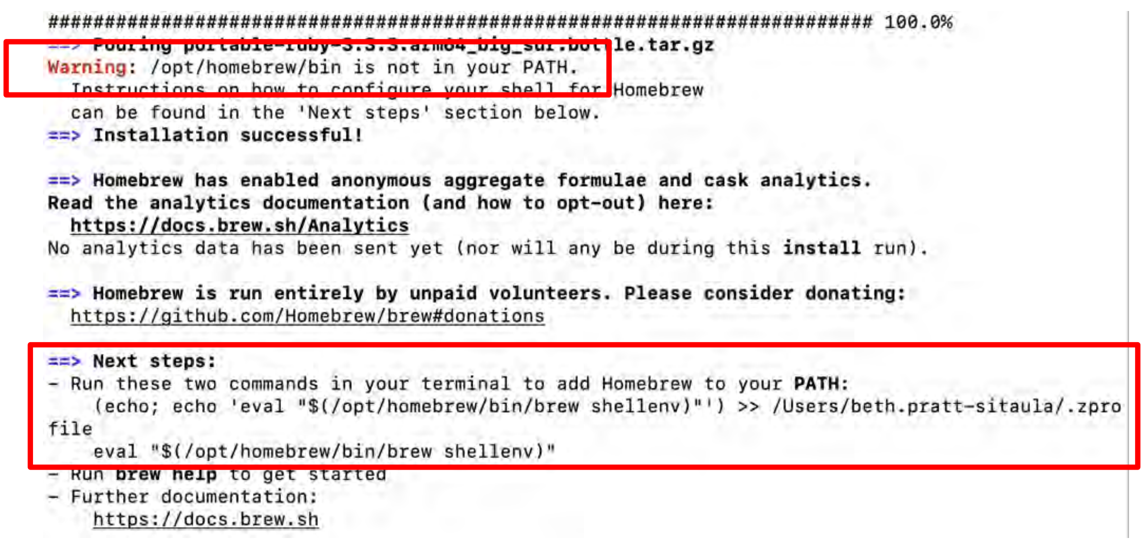
   

   Figure 6. Possible warning notice

   NOTE: You may need to install Command Line Tools for Homebrew.

2. Install *XQuartz* by running the following command on 'Terminal': **brew install xquartz**
   Enter your administrator password if prompted.

3. Install *Wine* by running one of the two commands, based on your MacOS version:
   [on macOS Catalina/10.15 and higher] **brew install --no-quarantine wine-stable**
   [on macOS versions older than Catalina/10.15] **brew install wine**

4. If you were able to install all the above dependences with no errors, you are ready to install ResIPy. Navigate to [ResIPy's GitLab page]() and scroll to the 'Downloads' section (Fig 7).

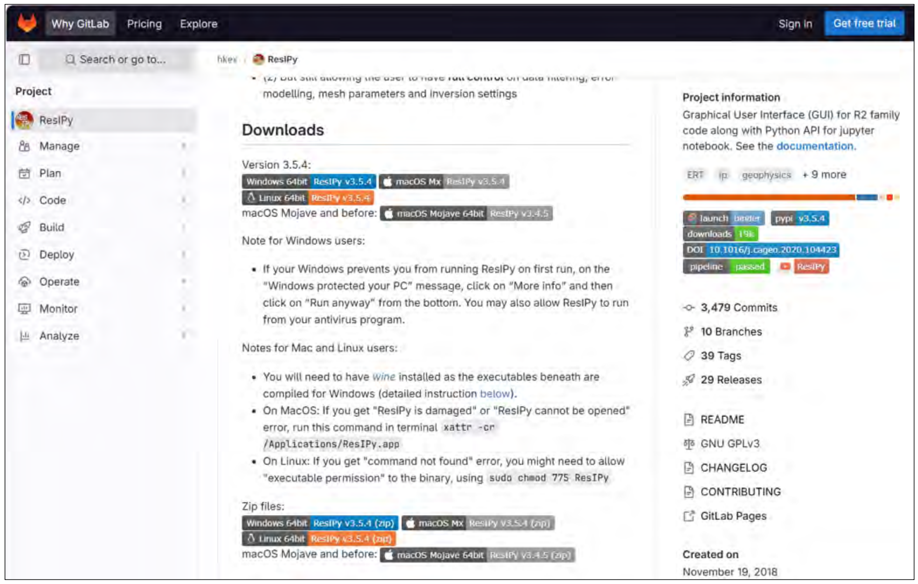


Figure 7. Downloads section of ResIPy's GitLab page

5. Double click the icon, directly underneath the 'Downloads' header, that matches your operating system. This will download a .dmg file. (Fig 8)

Figure 8. Download .dmg file

6. Double click on the .dmg file that you just downloaded. When the following window opens, drag the 'ResIPy' icon to the 'Applications' folder icon. (Fig 9)

Figure 9. Drag ResIPy to Applications

7. Navigate to your 'Applications' folder and double click on ResIPy.

   NOTE: If you receive an error message that "'ResIPy' can't be opened…", open 'Terminal' and run the following command (Fig. 10) to bypass this error message:
   xattr -cr /Applications/ResIPy.app
   Double click on ResIPy again.

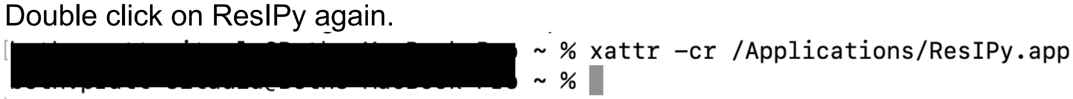


Figure 10. Bypass for MacOS error message

If a window similar to Figure 11 appears, then you have successfully downloaded ResIPy ☺

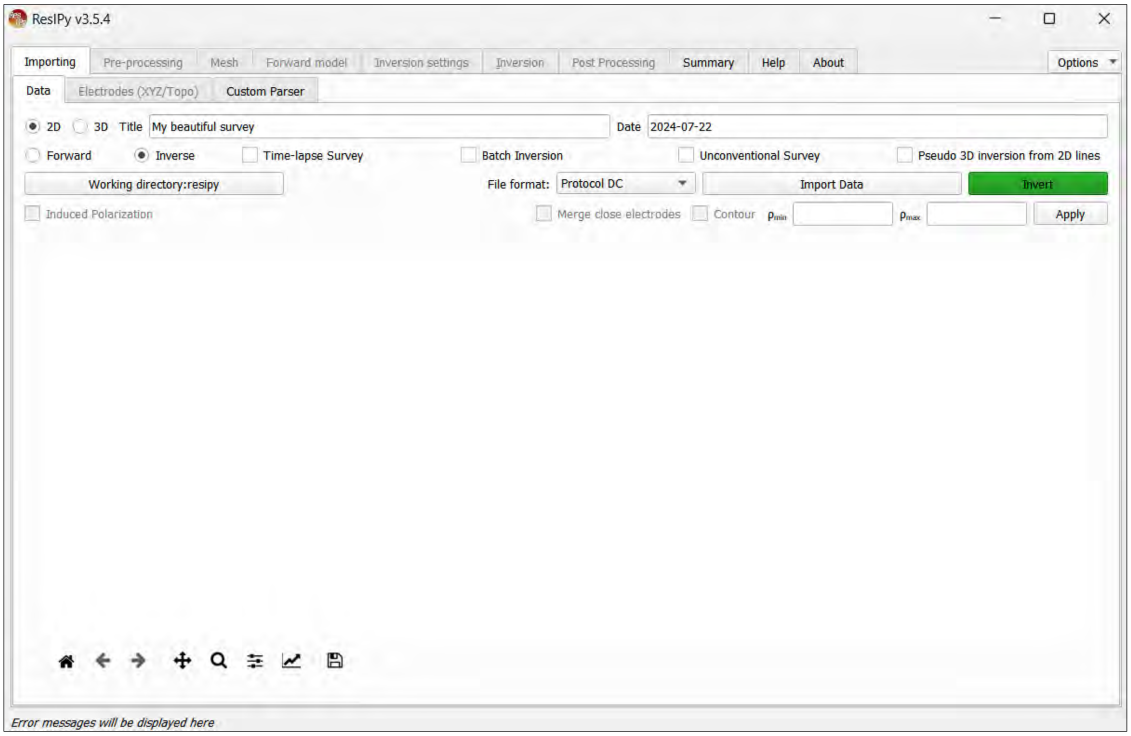


Figure 11. ResIPy window

References

Blanchy G., Saneiyan S., Boyd J., McLachlan P. and Binley A. 2020. "ResIPy, an Intuitive Open Source Software for Complex Geoelectrical Inversion/Modeling." Computers & Geosciences, February, 104423. https://doi.org/10.1016/j.cageo.2020.104423.

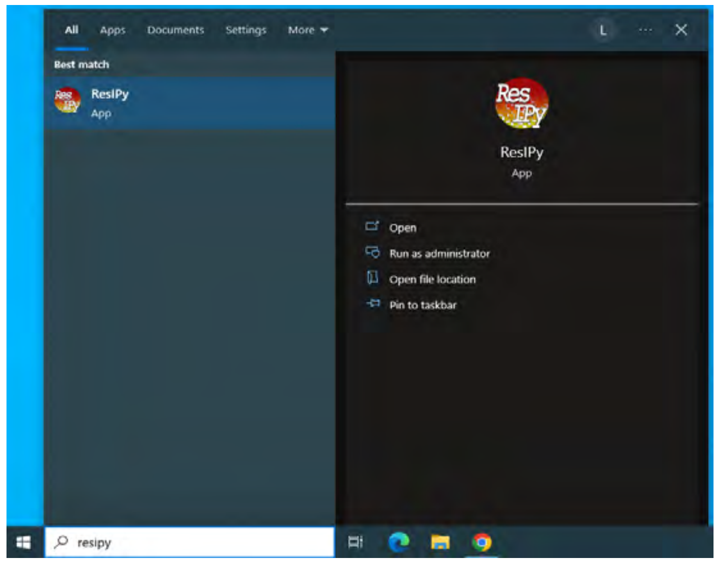
ResIPy Quick Guide

Lena Schwebs (University of Wyoming)

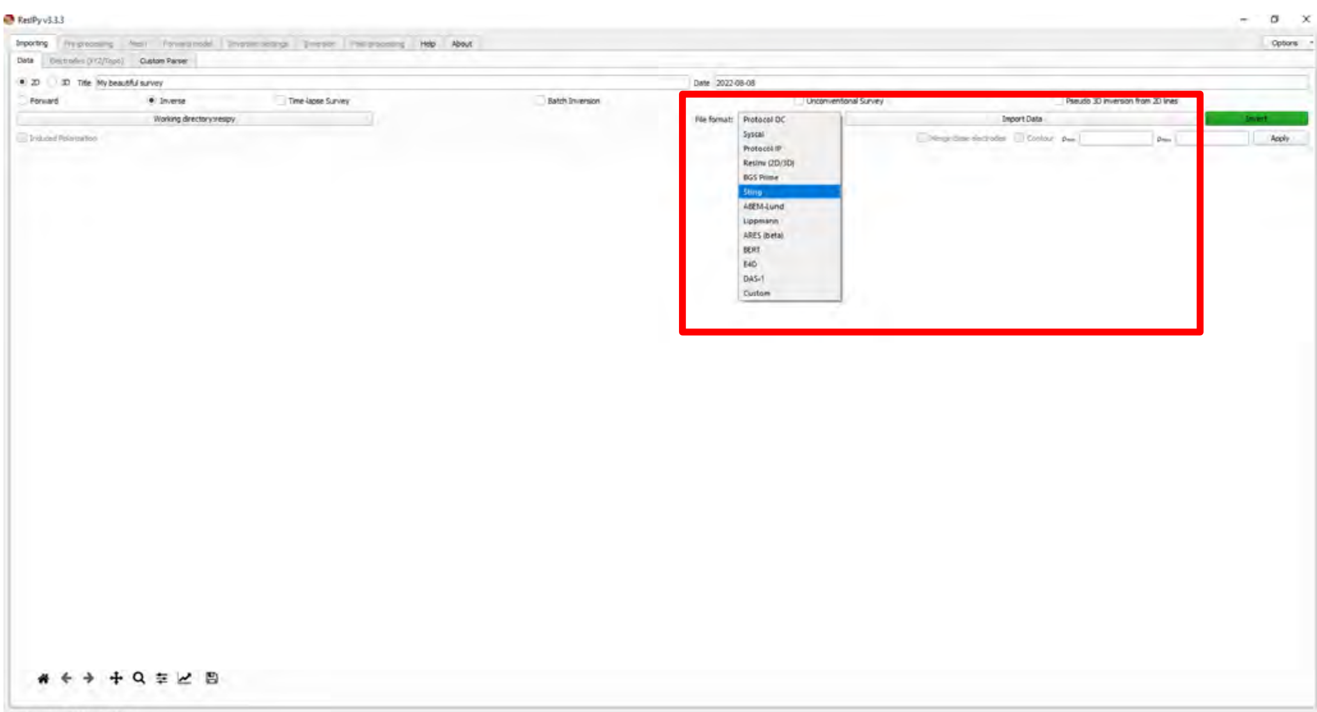
ResIPy is an open-source software for analyzing electrical resistivity data. This document is a short guide to get started using the software. It assumes that you already have data to analyze. See separate instructions for installing ResIPy if you have any issues with that part.

1. Opening ResIPy/Uploading Data

    a. Open ResIPy.



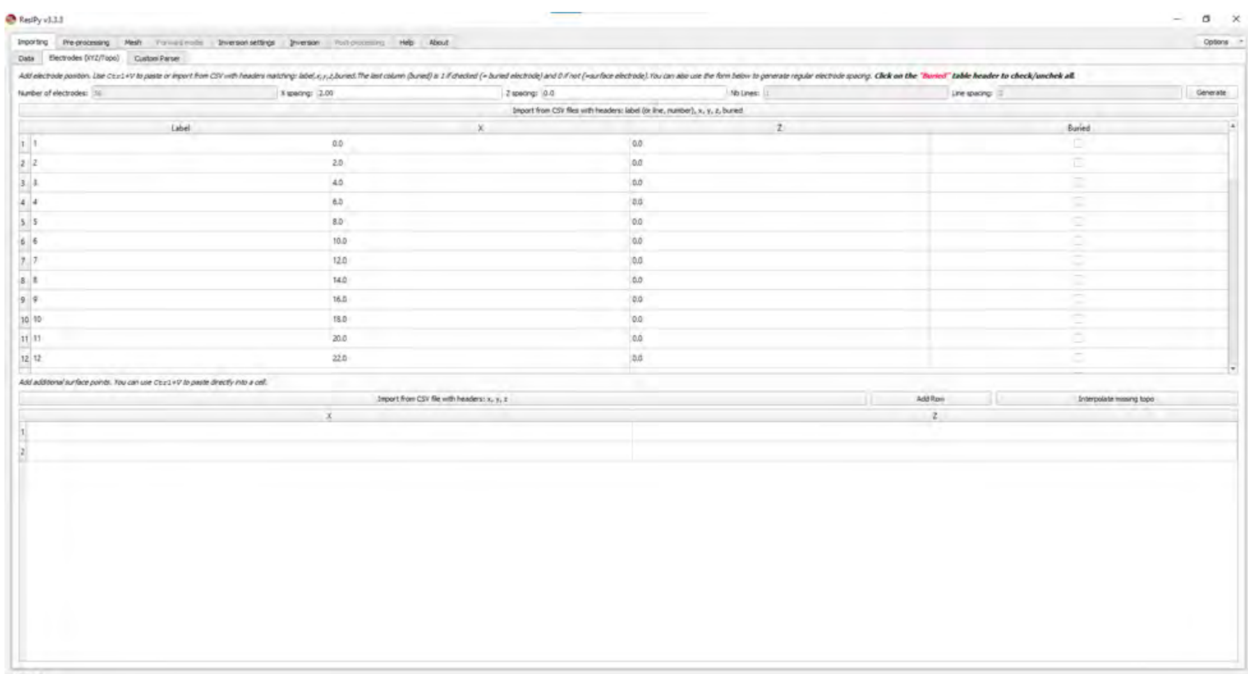
    b. Change the file format to **Sting** and click **Import Data** to find the *.stg* file you want to open.



c. Change **Title** from “My beautiful survey” to a more suitable name.

d. Your screen should now look similar to the below image.

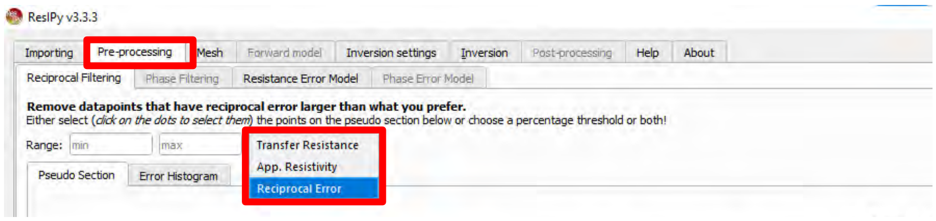
e. At this point, elevation data would typically be uploaded under the **Electrodes (XYZ/Topo)** tab. However, if your dataset is from a nearly level surface, this step will be skipped.



2. *Pre-Processing Data*

   a. Click on the **Pre-Processing** menu tab.

   b. Choose **Reciprocal Error** from the drop-down.



   c. Put **reasonable value (5-15%)** in the **Threshold** box left of the drop-down.

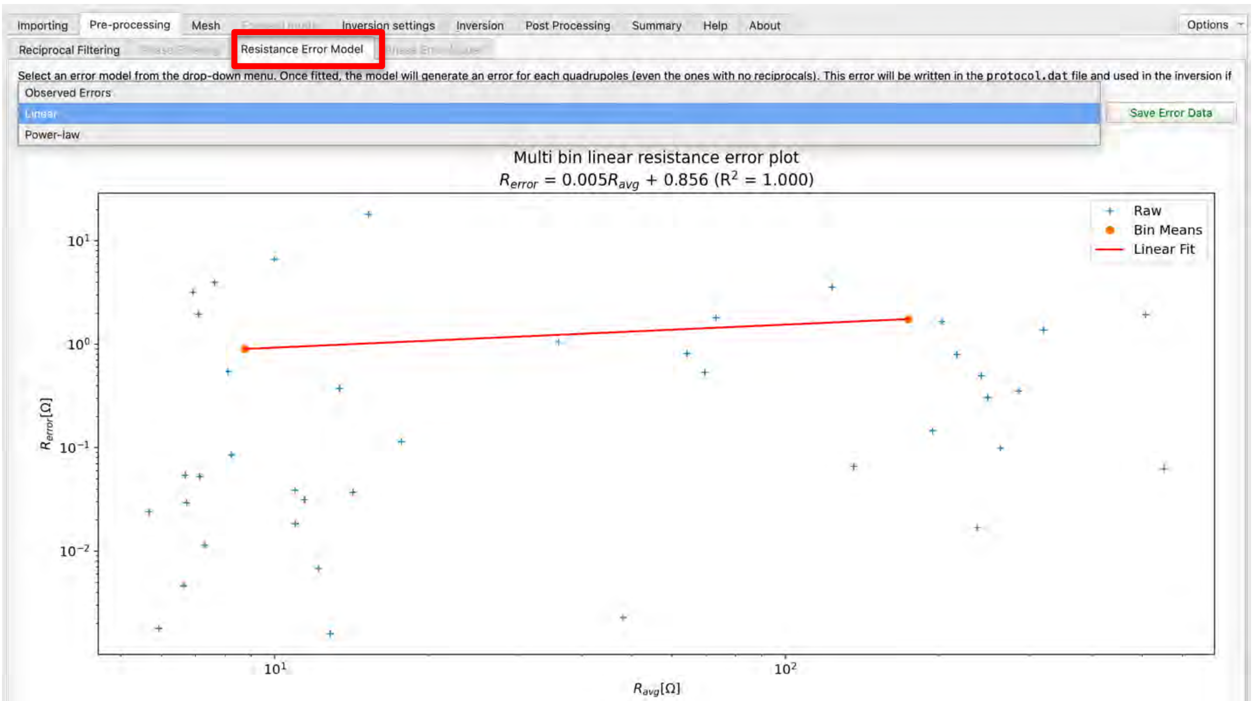
   d. Click **Apply Filters**.

   e. You should notice some points have been removed in the pseudo-section.

f. Click on the **Resistance Error Model** tab.

g. Select **Linear** from the drop-down menu.

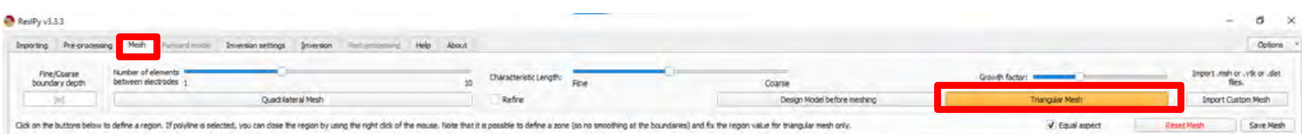
h. The image should change to include a red linear fit for the blue plus-sign errors.



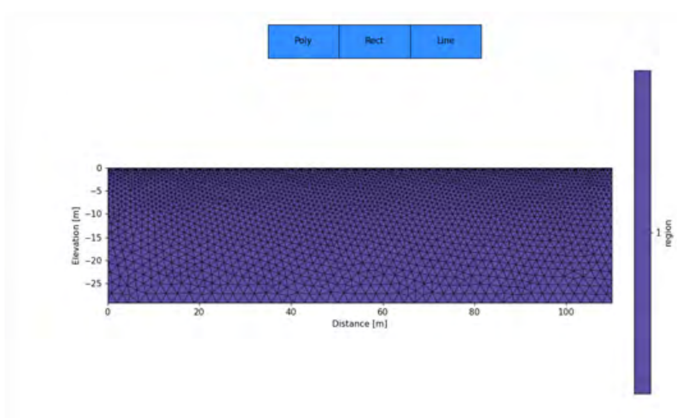
3. *Creating a Mesh*

a. Click on the **Mesh** menu tab.

b. Click on the yellow **Triangular Mesh** button.

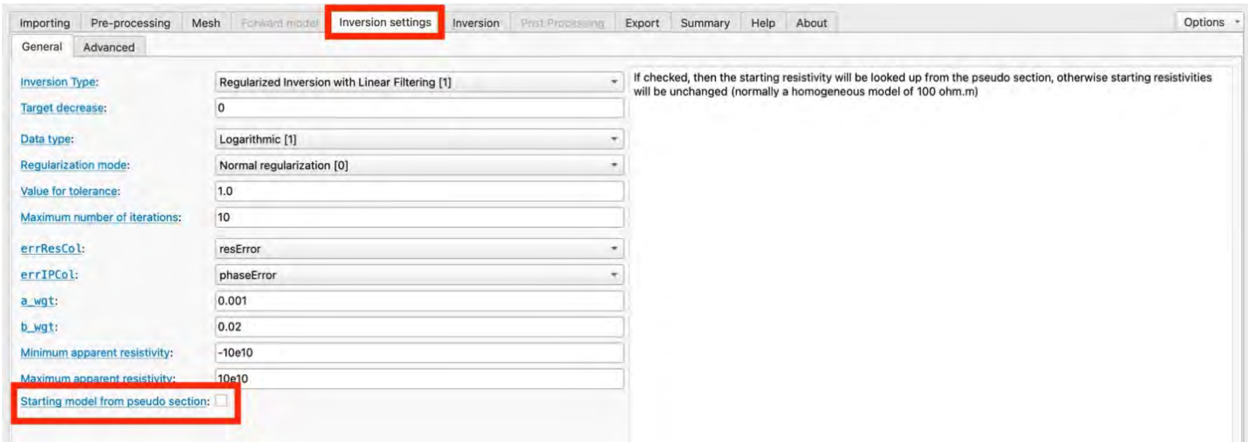


c. A mesh should be created that looks similar to this image.



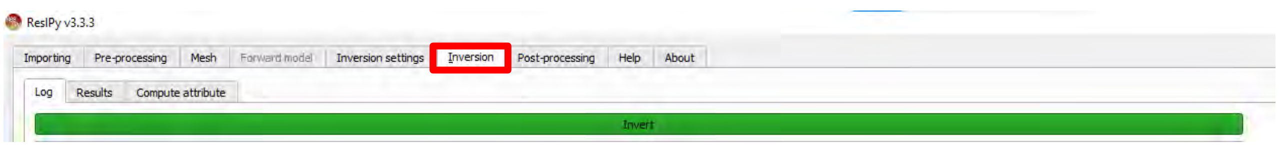
4. *Inverting the Data*

    a. Under the **Inversions Settings** tab, make sure to uncheck "Starting model from pseudo section" (Note: this step became needed in newer versions of ResIPy)



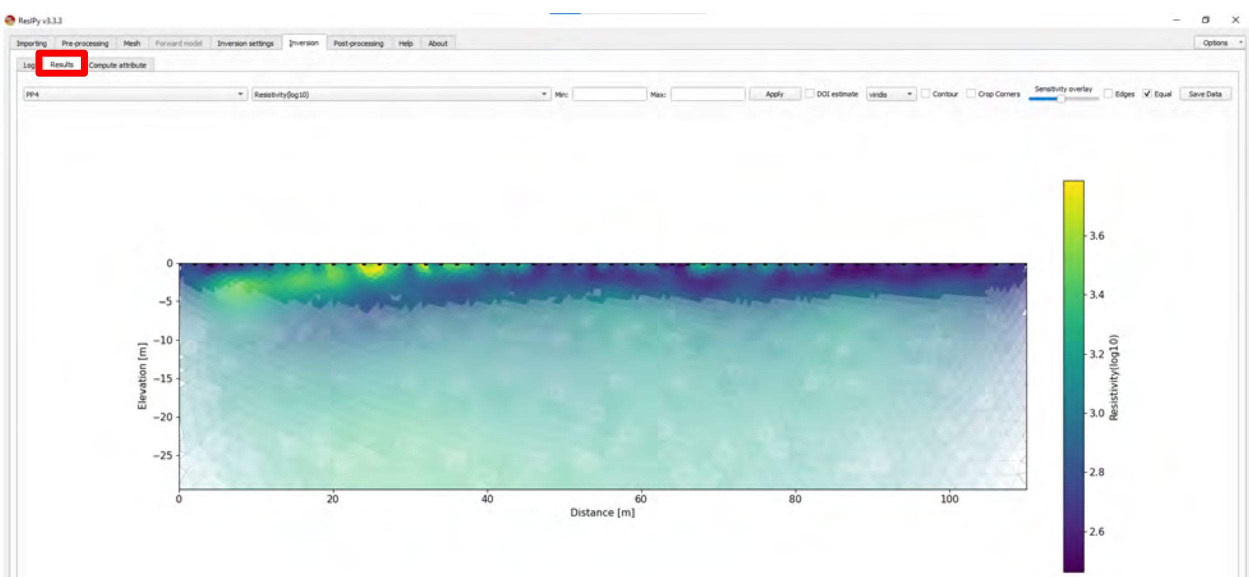
    b. Click on the **Inversion** menu tab.

    c. Click on the green **Invert** button.



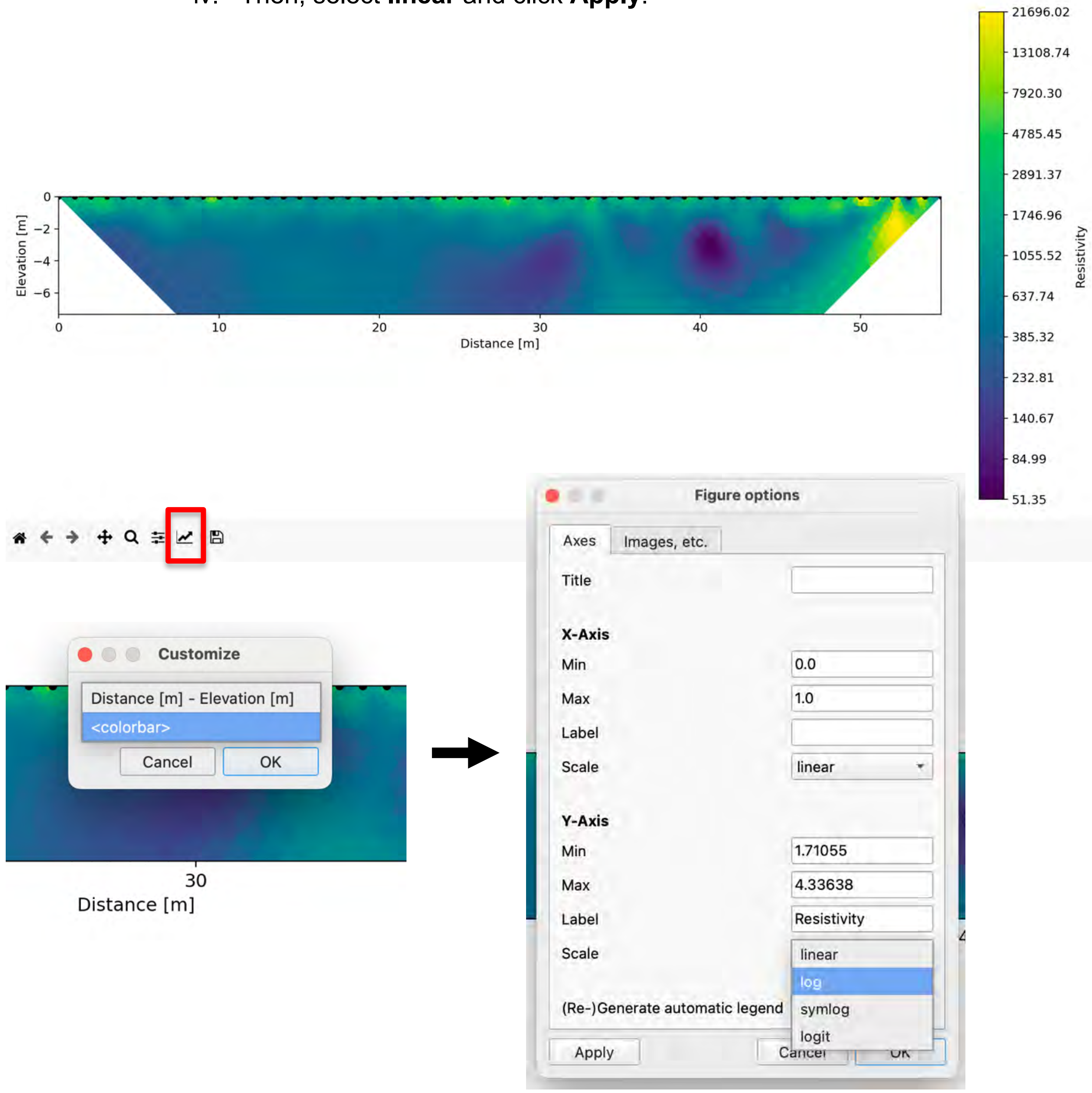
    d. The screen will begin to populate with the inversion stats. The program is set to do a maximum of 10 iterations, but it usually shouldn't take more than 3.

    e. Once the inversion is complete, ResIPy will automatically switch to the **Results** tab with the completed inversion such as the picture below.



f. You have now finished processing the resistivity data!
    i. It is recommended you keep the data set to **Resistivity(log10)**, check **Clip Corners**, and choose the color scale you prefer from the drop-down bar.
    ii. The other features you can play with to see what each one does and ask questions.

g. If your colorbar is displaying linear units for **Resistivity(log10)**:
   i. Click the edit figure button (bottom screen, second to last icon, upward trend icon).
   ii. Select **<colorbar>** from the drop-down.
   iii. Under **Y-Axis**, select **log** from the **Scale** drop-down and click **Apply**.
   iv. Then, select **linear** and click **Apply**.



Seismic Refraction, Unit 3: Seismic Survey Preparation—Additional Supplies, Planning, Safety, and Field Notes Recommendations

Sarah Kruse (University of South Florida)

This document is intended to augment other guides specifically about the data collection and analysis and help people newer to seismic surveying be ready for the field.

Additional supplies

EarthScope Primary Instrument Center (EPIC) does not typically provide all the supporting supplies that are needed or recommended for a seismic refraction survey because needs vary and because some are prohibitively heavy to ship repeatedly. However, EarthScope may be able to help low-resource institutions purchase the supplies the first time. Contact education@earthscope.org if this would reduce use barriers for your course.

- 1–2 100-meter measuring tapes
- A tarp on which to place the Geode and battery and laptop if you are working in a dusty or damp setting. This will make it easier to keep the connectors clean. Suggestion: lay out the tarp and put the equipment on the downwind side. That way if wind comes up or it starts to rain you can quickly fold the upwind half of the tarp over the equipment. (Even more luxurious is a camp chair and even a folding table. Even if you do not put it underneath, have a tarp available in case of rain.
- A full-length sledgehammer: 10-12 lbs makes for a good hit and can be swung by most people.
- A roll of electrical tape to attach the trigger to the hammer. Remember to make sure the dot is on the side facing the hammer (see trigger). Suggestions: mount the trigger 6 inches above the head of the hammer on a narrow side of the hammer. Wrap electrical tape tightly around the trigger + hammer all along the length of the trigger. Then tape the trigger cable higher on the handle as well.
- 5–6 camping stakes per 100 m tape to hold the survey tapes in the ground. Use stakes to hold both ends, and if there is topography, you may want to hold intermediate points to the ground as well. Be careful about the stake at the far end of the line—you don't want to pull the survey tape off the spool. You can put a couple of wraps of the survey tape around a stake at the far end of the line, if you don't leave the tape in that position for too long. Any folding from the wraps should come out as you rewind the tape. Rewind the survey tapes carefully before you move any tape to a new location, a tangled tape or one that does a 180-degree twist can cost a lot of time to fix.
- A small sledgehammer or other hammer to pound the stakes into the ground if the ground is hard.
- A 12-V car or motorcycle battery and 12-V battery charger
- An umbrella for sun, if it is sunny and not too windy. It can be hard to see the computer screen in full sun.
- Provide a set of work gloves for the student swinging the hammer. May not be needed, but nice to have on hand (no pun intended).

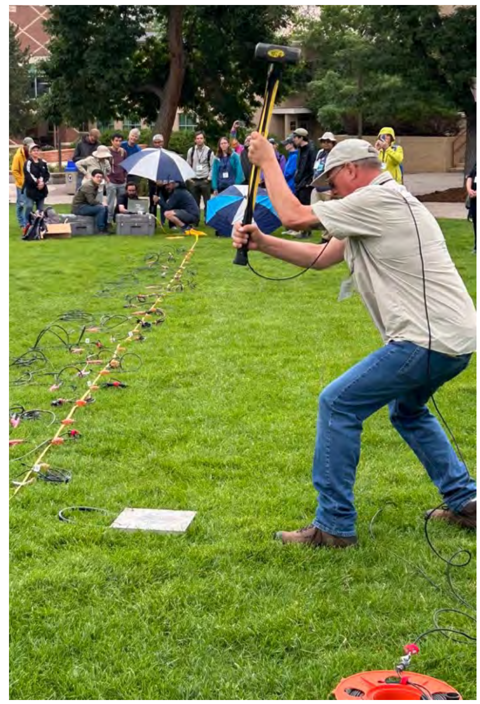
- Ear plugs. If you are using a high-density plastic strike plate, ear plugs may not necessary but if the strike plate is metal, they should be used. You can get these at Home Depot or a hardware store. Eye protection is also a good idea.
- Optional: If you are doing a long survey (shots more than 100 m away from the Geode) you may want walkie-talkie radios so that students sitting with the Geode can tell students when to swing the hammer.

Before data acquisition

- Research what you might expect in the subsurface at your site. In some places the water table rather than sediment-bedrock contact may produce the first refracted arrival. To collect and assess your data it can be very useful to have some idea of both the depth to the water table and the depth to bedrock beforehand. If the water table is shallow, you may be able to auger to it and measure the depth with a survey tape (good enough to compare with the seismic data). Local well drillers or someone in your campus physical plant may have a general idea about these depths.
- Work through the Design a seismic refraction survey exercise (Unit 3 Part 1, Exercise 1) for your guesses on subsurface structure.
    - Recall from Unit 1 velocity of soil is ~ 400 m/s, velocity of water is ~1500 m/s, and velocity of bedrock is ~2000 m/s. The table on the last slide of the Unit 3 Part 2, Data Analysis and Interpretation presentation shows that these numbers lie within a range.
    - Typically, soils may be ~200 m/s–800 m/s above the water table, and >~800 m/s below the water table. Weathered rock will be in the range of 1000–2000 m/s, while intact rock is >~2000 m/s.
    - There is a nice table in https://pburnley.faculty.unlv.edu/GEOL452_652/seismology/notes/SeismicNotes10RVel.html. (We are measuring P wave velocities.)
    - Going through this process will help you ensure that you have enough space at your site to capture the refracted wave.
- If you have no idea about the subsurface, it can be useful to do a preliminary "walkaway" test in which you place the geophones quite close, such as 0.25 or 0.5 m apart. Then you start with a shot at one end of the line and look to see whether you capture a slope break along this line. If you don't see a slope break, then move the shot one array length away and shoot again. (If you have put your geophones in a line starting near zero on a survey tape It can be useful to have a second tape laid out the other direction from zero to easily find the new position of the shot.) Continue until you see a slope break. At this point calculate the distance between the shot location and the slope break. Then you can decide what geophone spacing you want to use for your actual survey. It is good to set the geophone spacing close enough that you will capture the direct arrival on at least 3–4 phones before you see the slope break.
- Make a checklist for things you will take to the field and bring home from the field. (Sample checklist supplied.)
- Review the *How To: Seismic Refraction Field Set Up* video (https://www.youtube.com/watch?v=AyOFG6ZA540).

- The night before the survey, charge the 12V battery.
  The day of the survey, check with a voltmeter that the 12V battery is charged (>12.7 V).
- The night before the survey, charge the laptop computer. (Bring the car computer charger to the field—EarthScope provides this, in case the laptop doesn't hold its charge.)
- If you have an option for when to run your survey, try to avoid windy days. Or if the wind tends to come up in the afternoon, schedule in the morning, if possible.

During data acquisition



- Swing the hammer safely and effectively; make sure students swing the hammer with the trigger on the upper side of the hammer, so in case they miss the strike plate and hit the ground they don't smash the trigger into the strike plate. Make sure the cable is not in the path of the hammer blow. Draping the cable over one's shoulder can be a good way to keep it out of the way. The person operating the sledgehammer should aim to have the hammer head drop straight down and back up again without a double bounce if possible. People with back issues should not be the ones doing the sledgehammer.
- Hammer operators and nearby people should use ear plugs if using a metal strike plate. Eye protection is also a good idea.
- Students should make a sketch of the experiment in their field notebooks, carefully noting the locations of all geophones and the shot location corresponding to each file. The most common mistake is that students (or faculty) fail to update the shot location in the Geode when the shot location is moved. Then the shot location is improperly recorded in the data file. This is usually an easy fix but only if the correct shot location is recorded in a field notebook.
- Make sure students note the direction of any survey. For example, on a line that runs NW–SE, is the zero position on the survey tape at the NW end or the SE end?
- Make sure the student at the Geode and the student swinging the hammer double-check with each other the hammer location before the swinging starts. This helps to avoid the problem of not recording the shot position correctly.
- After you are finished, if the pounded-in stakes don't come out easily, hit them on the side to create a bigger hole to pull them out.
- Pull up geophones before you pull up the survey tape. (If working in tall grass, geophones alone may be hard to find.)
- Use the checklist again at the end of the day to make sure no equipment is left in the field.

Date:
Start time:
Group number and names:

Equipment Check Out Log Seismics			
	Load morning	**Load field**	**Comment**
Seismic Equipment Box			
24 Geophones (orange)			
1 spare Geophone (orange)			
1 geophone take out cables			
2 trigger extension cable			
trigger			
spare trigger(s)			
Geode (large yellow box)			
yellow cable geode-to-computer box			
power cable			
Geode-to-comp box (gray)			

2 car or small 12V batteries (fully charged)			
volt meter			
laptop computer (fully charged)			
computer power cable			
car computer charger (opt)			

1-2 100-m tape measures			
small hammer (if using stakes)			
stakes/flagging			
tarp			
umbrella (to shade screen from sun/rain)			
electrical tape			
laser ranger finder			
handheld GPS (or phone GPS)			

ear plugs			
eye protection (sun or safety glasses)			
gloves			
sledge hammer			
strike plate			

Date ______________________

Location ______________________

Goal ______________________

 # geophones ______________________

Geoph spacing ______________________

Field team ______________________

Weather ______________________

GPS 1st Geoph ______________________

GPS Last Geoph ______________________

Sketch of field site showing line orientation any key local features

	Line location (m)	# shots	file name	notes
Stack 1				
Stack 2				
Stack 3				
Stack 4				

Seismic Refraction Unit 3: Geode Field Quick-Start Guide

Greg Chavez (EarthScope Consortium, greg.chavez@earthscope.org)
Updated by Ann Mariam Thomas (EarthScope Consortium)

Background

Geode users, this guide is intended to help you quickly start a basic Geode survey. Note that all surveys are different, and the suggestions listed in this guide may not fit your scientific objectives. It is up to you, the user, to identify the specific settings that your survey requires. For typical acquisition parameters and practices for near-surface studies, you can refer to Near-Surface Seismic Refraction Surveying Field Methods by Deborah Underwood.

All EPIC (EarthScope Primary Instrument Center) Geodes that return from the field are tested, and during this process any data and configuration settings are erased, and the unit is reset to factory default settings. This is done for two reasons: (1) we don't want to backtrack all the user settings in order to get the control software back into a standard configuration, and (2) if the software doesn't detect any previous configuration information, it will automatically solicit the user to enter all the valid information it needs to successfully collect a dataset. This feature makes startup for a new user fairly easy and straightforward.

If you prefer a visual start guide for your Geode survey, check out the How To: Seismic Refraction Field Set Up video (https://www.youtube.com/watch?v=AyOFG6ZA540).

Part I: Equipment Setup

Note: Always fully charge your laptop the night before your experiment to avoid a max current draw situation in the field that may needlessly drain your field batteries.

2. **Plant the geophones** at your desired locations and **connect them to the takeouts** on the geophone takeout cable. Geophone intervals of 1–5 meters are typical for near-surface surveys. When planting geophones, it is important to keep the geophone spike vertical and push it as far into the ground as possible. Ensure that each geophone is secure by gently trying to twist it.

3. **Secure the trigger cable** onto the shaft of your sledgehammer using PVC electrical tape.

4. **Connect the Geophone takeout cable and the trigger** input to the Geode connectors with the following symbols.

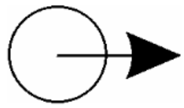
Geophone Takeout Cable

Trigger

Note that you will need an adapter if you have Cannon NK27 connectors on your takeout cables.

5. **Connect the digital interface cable** to the Geode. You will recognize the digital interface cable as it has identical connectors on either end, neither of which have pins.

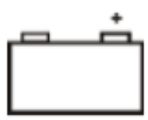
Geodes often have more than one digital interface cable, so you will want to connect to the one with the OUT symbol, which indicates data is transmitted OUT of the Geode back toward the storage and control device.



Digital Interface
Cable (OUT)

5. Connect the other end of the digital interface cable to the connector on the small **network interface box (NIB).** It is a small box, 5 cm square, with a pinless MIL connector on one side for the ES-3000/Geode interface cable and an RJ45 connector on the other. Connect the RJ45 connector to the RJ45 port on your field computer. If you have a NIB with a toggle switch on one side, put the toggle switch in the ON position.

6. **Connect your 12V power source** to the Geode by connecting the power cable to the connector with the symbol



Power

Your completed setup should look similar to Figure 1.

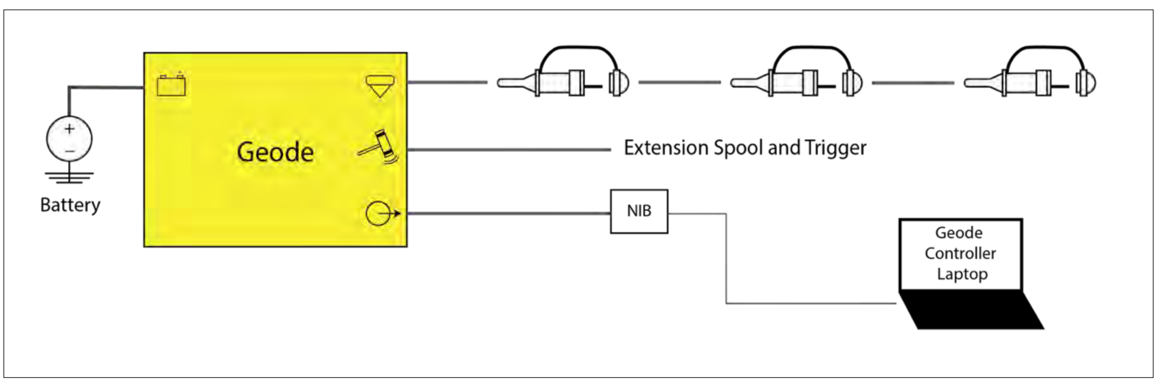


Figure 1. Equipment setup

7. Check if the blue LED light on the Geode is blinking. This indicates that the Geode has been successfully activated. If the blue LED is not blinking, toggle the Enable Power switch on the NIB. If this does not work, try pressing the red test button on the Geode. If the blue LED turns on after pressing the test button, the 9V battery in your NIB Box may need to be replaced. If the light does not turn on after pressing the button on the Geode, then your Geode is not connected properly to 12V.

Part II: Data Acquisition using *Seismodule Controller*

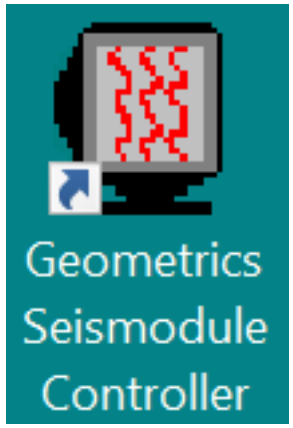


Figure 2. Desktop icon for the control software

1. After your equipment is connected and powered on, open the *Seismodule Controller* application (Fig. 2) on your field computer. If the software cannot detect any seismographs (Fig. 3), select "Retry." Sometimes you need to try more than once for the software to detect the equipment. If the software still cannot detect your geophones, check the connections on the Geode and ensure that you have completed every step in Part I.

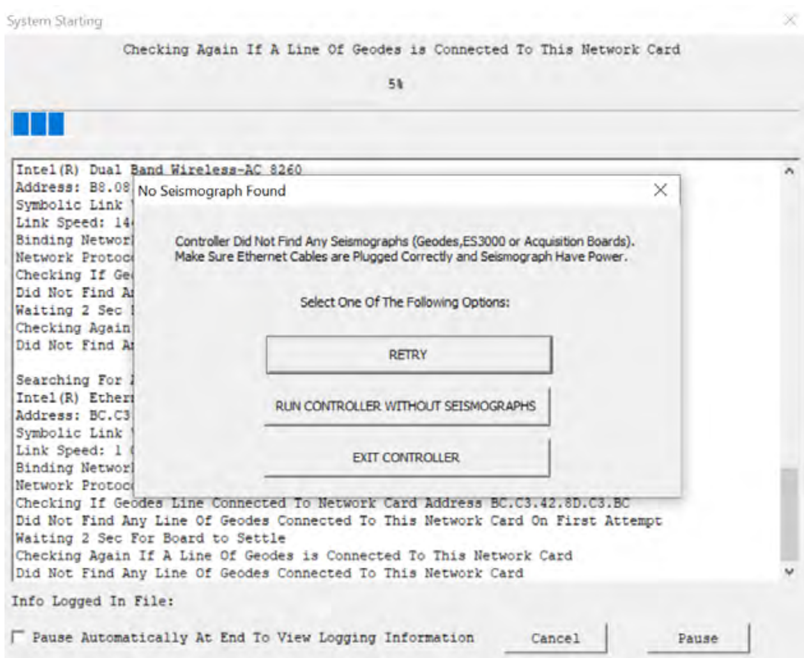


Figure 3. 'No Seismograph Found' message on Seismodule Controller

Once your equipment has been detected, you will be prompted through the following series of menus to create an acquisition configuration:

a. **Survey name:** Enter a helpful survey name and the initial line number (typically 0).

b. **Acquisition correlation:** Enable or disable correlation. Disable correlation if you're not correlating with an outside signal. In most cases, disable correlation will be checked. Keep "Pilot Channel #" at its default value of -1.

c. **Acquisition stack parameters:** We recommend checking "Auto Stack," "Stack Polarity Positive," and "Display Intermediate Stacks." You can set a stack limit that will automatically save files and clear memory when that stack limit is reached. If you are working with an inexperienced crew, we recommend setting this number to a high value (ex. 10; but at least 3 is good), and using the Hot Keys to save and erase manually when the desired stack limit is reached. The Hot Keys for save and erase are: F7 (Save) and F2 (Clear Data). The "Replace" option will not stack your data.

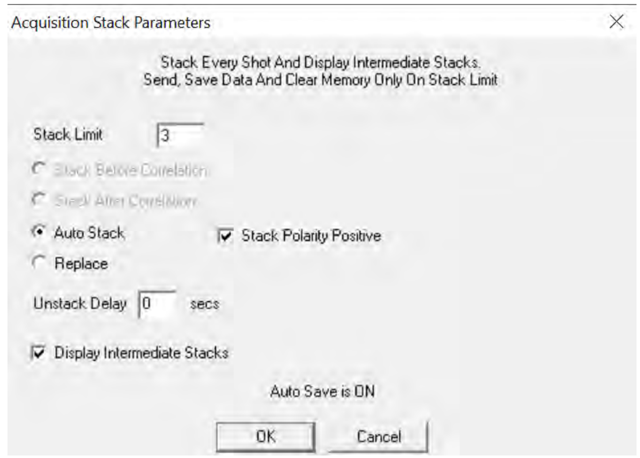
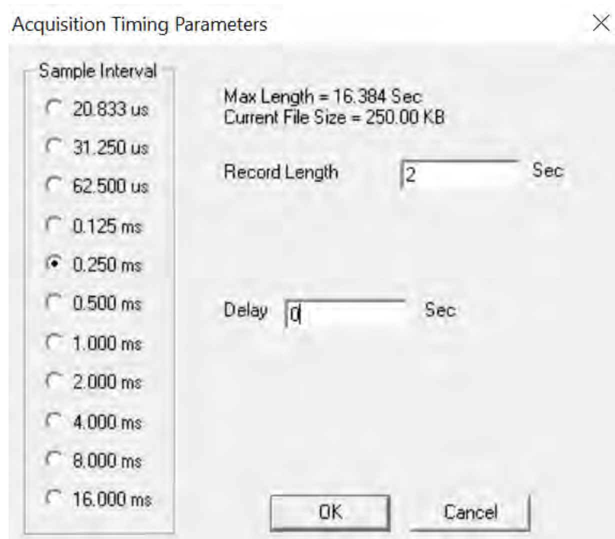


Figure 4. Setting Stack Parameters

d. **Acquisition timing parameters:** Set the Sample Interval (0.250 ms), Record Length (2 s), and Delay (0 s). (Fig. 5) The values given in parentheses are good options for most local strike plate cases.

e. **Acquisition filter parameters:** We do not recommend setting filters at this stage (set both options to "FILTER OUT").



f. **Geophone interval:** Set your geophone spacing in meters or feet.

g. **Gains:** High/Low gain selection. We recommend the default setting of "All Low Gain".

h. **Geometry menu:** This menu shows the channel use setting and spacing for each geophone channel (Fig. 6). You can set your first shot location here, in the unit you selected for your geophone interval (also given in the lower right corner of the window). For example, if your geophone interval was set to 5 meters and you plan to shoot 10 meters away from your first geophone, you would enter -10 as the "Shot coordinate." Typically, you will take 3 shots at each geophone location. You will need to manually roll the shot location after every competed stack by entering the next location in the box. Use the F3 Hot Key after you save the previous shot. Note: The Geode also has an auto roll capability for more experienced users.

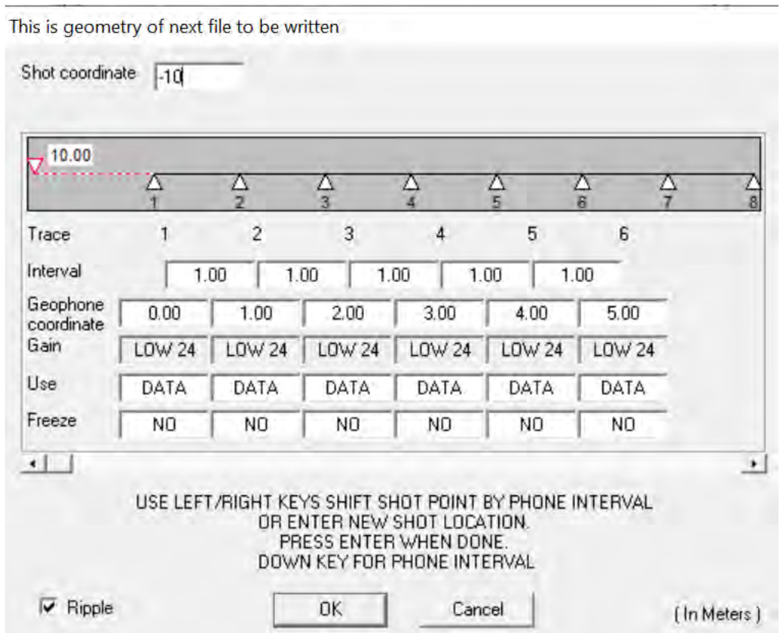


Figure 6. Set Experiment Geometry

i. **Storage parameters:** Select a file start number and a file format. If the start number suggested by the software is any number other that 1, you may have previously saved files in your directory. You should move these old files or change directories if you are starting a new survey. Auto save will save a file after every hammer strike or if the stack limit is reached, depending on your selections in the “Acquisition Stack Parameters” menu. If you plan to use Hot Keys to select and save your files during the survey, uncheck Auto Save. We recommend the SEG-2 file format.

j. **Operator log:** Select your log preferences. All selected information will be listed in the header of the log file. You can keep the default template or enter your own log items and descriptions.

k. **Trigger Options**: Set the trigger sensitivity, hold off, master trigger, and arm mode. Setting the trigger hold off to 0.5 s and keeping the other settings at their default values can be a good option for typical cases. I have never needed to adjust the sensitivity from the default of 50%, because when most triggers fail, they fail completely, and once fully failed, modifications to sensitivity do not have any impact. By default, the master trigger is always the Geode closest to the CPUI. If you need to move the master trigger to another Geode in your survey line, you can select that option here. With Arm Mode set to Auto, the trigger will automatically re-arm after each shot.

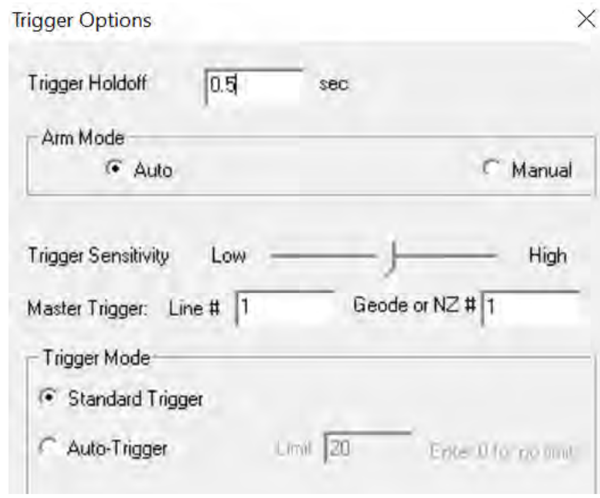


Figure 7. Set Trigger Parameters

That concludes the basic survey setup on *Seismodule Controller*.

Troubleshooting Tip: If you lose track of your acquisition settings and/or forget what changes you have made, you can always adjust any of the initial acquisition settings using the toolbar menu at the top of the *Seismodule Controller* software. Alternatively, you can use the following reset steps to restore the unit back to factory defaults and start fresh.

T1. In the ".System" menu at the top of the software, select "Test" --> "Troubleshooting: Reset All Parameters to Defaults When Program Restarts."

T2. Click "Yes" and hit the red X at top right to close out of the software. Click "Yes" to terminate the survey.

T3. Erase or move your saved logs and restart the *Seismodule Controller* software.

2. Set the NIB toggle switch to the center OFF position. This will allow the software to close and power down the Geode properly when the survey is concluded.

3. **[Optional] Setting up the user interface.** After the main configuration options are selected, you are left with a geometry toolbar at bottom and several overlapping menu screens on *Seismodule Controller*. I will suggest a few options to make this display a little more user friendly.
   a. Right click on the Geometry toolbar at the bottom and select "Geometry Tool Bar Display Setting" (Fig. 8).

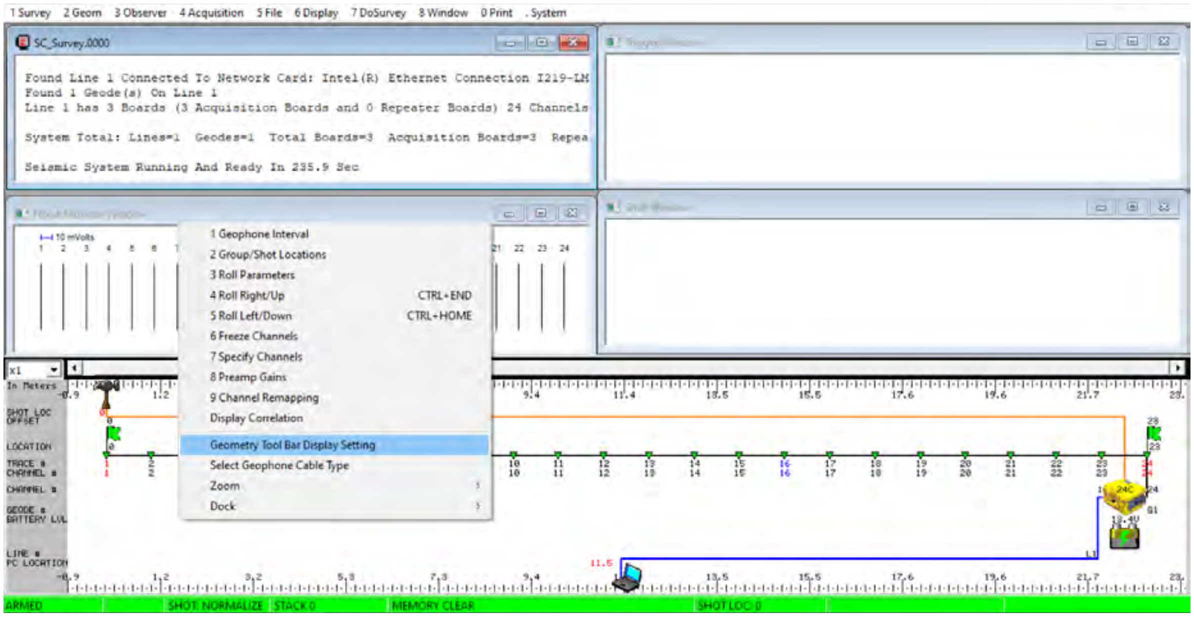


Figure 8. Selecting Display Settings

b. Uncheck "Show PC," "Show Battery," "Show Flag," and any others you think are unnecessary (Fig. 9).

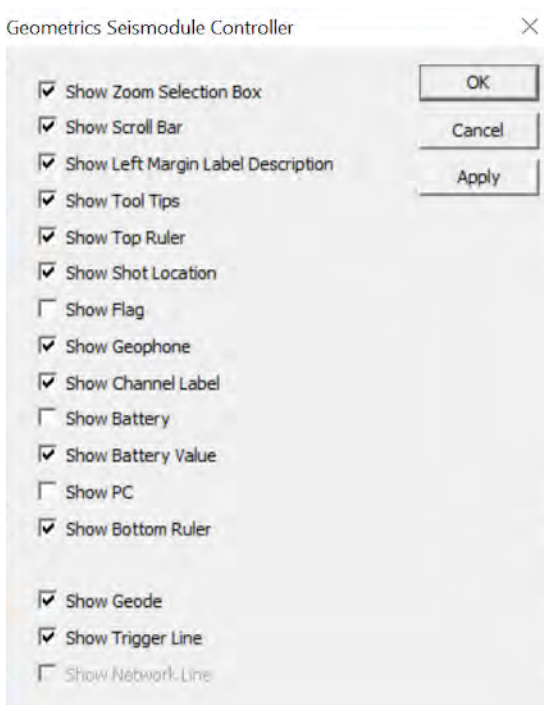


Figure 9. Checkbox selection in Geometry Toolbar Settings

c. In the "Window" menu at the top toolbar, uncheck the "Pilot," "Spectra," and "Trigger/Gun Monitor" Windows. Then, select "Tile all Windows Vertically" (Fig. 10). You should be left with a setup that looks similar to the window shown in Figure 11.

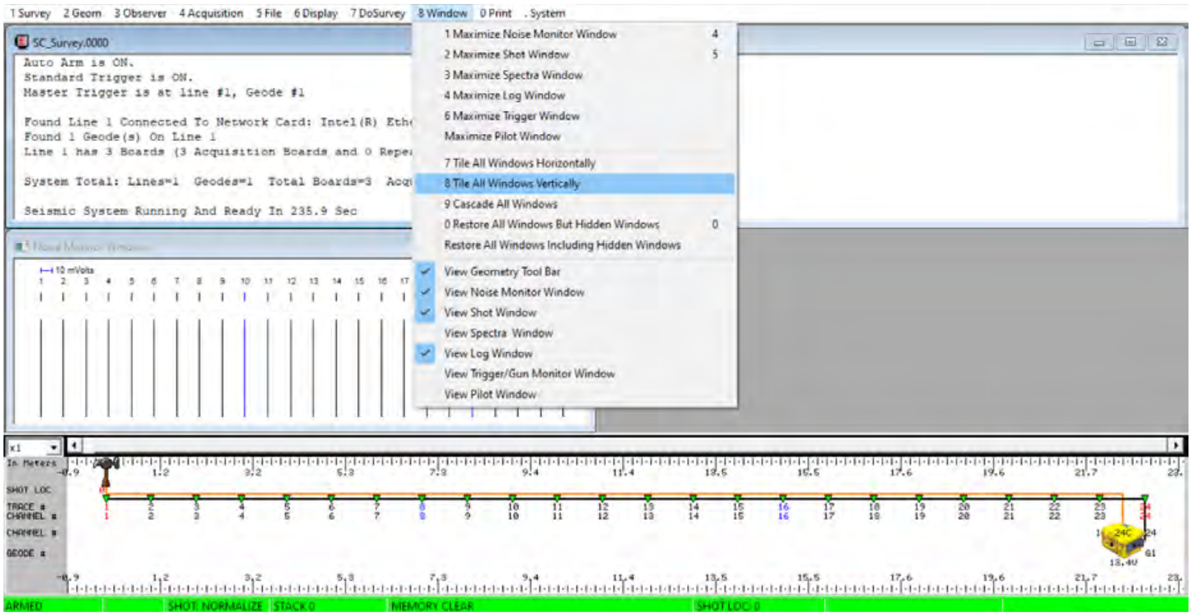


Figure 10. Checkbox options for the “Windows” Menu

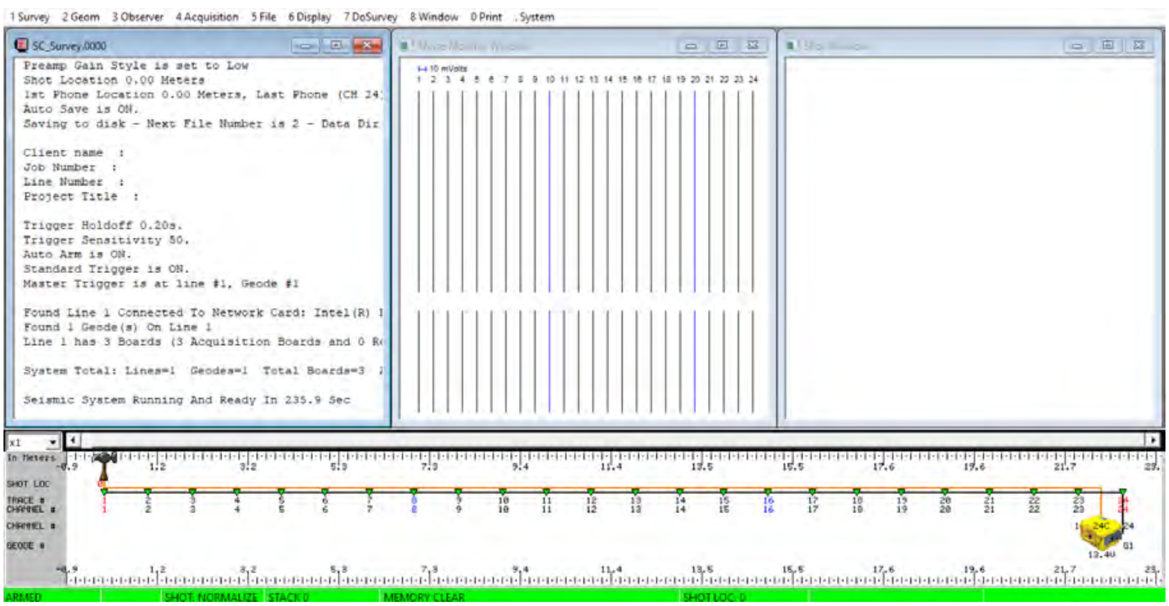


Figure 11. Appearance of Screen just prior to Shooting and Acquiring Data

4. **Stick test your geophones.** Bang the ground near each geophone with a stick and check if they react in the Noise Monitor Window on *Seismodule Controller*. Mark any unresponsive geophones with a marking tape and record them in your field notes. Leave a note in the shipment box about unresponsive geophones upon equipment return. At this point you are ready to shoot and acquire data.

5. **Perform your hammer shots**, after verifying that the bottom status bar is green (‘Armed’ mode, Fig. 12). Table 1 lists the possible modes of the status bar. When striking the metal plate with the hammer, make sure that you do not let the hammer bounce on the plate. This can lead to a false trigger.

i. More than one shot (hammer blow) at the same location, helps to determine noise vs real data.
ii. A minimum number would be 2 shots at 3 locations along the survey line (typically both ends and the middle).
iii. More ideal would be 2-3 shots and ~1/3 of your geophone locations.

Figure 12. Armed status

Table 1. Status bar modes

Status	Description
Armed	Ready to acquire data
Disarmed	Data acquisition disabled
Acquire	Collecting data on A/D cards
Busy	Undertaking system management
Sending data	Transferring data from A/D cards to computer
Receiving Pilot	Getting pilot from pilot channel
Sending Pilot	Transferring pilot to A/D cards to use correlator
Processing Data	Undertaking correlation or other signal processing

Keep detailed field notes as you change the geometry setup and shot locations of your experiment. Ensure that such properties are updated in the *Seismodule Controller* software for future visualization and analysis. Changes after initialization can be made using the top toolbar menu (e.g., you can access the Geometry menu by navigating to “2 Geom” on the toolbar and then “3 Group/Shot locations”).

6. **Transfer data files.** If you will be doing the data analysis on a different computer than the field laptop, save a copy of the raw data (.dat files) to a USB stick/external drive to transfer to the other machine.

Tips: Default setting has Geophone-1/channel-1 starting at the pigtail end of the cable. I prefer to reverse the order and have channel-1 starting at the first Geode location. To reverse the channel sequence, select the “9 Channel Remapping” option in the Geometry Toolbar Settings shown in Figure 8. Check the “Enable Channel Remapping box” on the bottom right corner and then check the “Reverse Channel Order” box on the top of the window. Don’t forget your Hot Keys. They are an easy and powerful way to navigate complicated software. Ideally, once you are set up you should be able to run the entire survey using only four Hot Keys. When working on a field course survey with students, for example, you may have some false trigger or bad hammer swings. In this case it might be useful to turn off the Auto Save and use the Hot Keys to save and erase only the known good data files/hammer strikes.

Conclusion

We hope this document will help guide you in easily setting up and running a survey using the Geode Software. The options used in this demonstration are not ideal for every experiment but should provide the user with a reference and some setup experience before a field survey.

Storage and return: There are a few things we would like you to do and not do when handling and returning the equipment

- ***DO NOT wind the cables around your shoulder and elbow (like an extension cord), rolling or winding the cables causes internal stress on the wiring and will lead to cable failure. Cables should be loaded into the boxes or barrels spaghetti-style (Fig. 13). Do not spool them in.***
- ***Mark any bad takeouts or geophones with a marking tape and leave a note in the barrel or box.***
- ***Replace all caps on connectors and keep the connectors clean. Keep and return the Geodes clean. Thank you.***

Figure 13. Proper Spaghetti-style method for storing Geode cables

Seismic Refraction Unit 3: Data Processing Using Pickwin

A. Parsekian (University of Wyoming)

This guide is intended for users of the Geometrics Geode seismograph system. The following steps lead the user through how to open the raw data files and how to generate images and tabular data that students can then interpret using the Excel-based workflow provided with the GETSI module Measuring Depth to Bedrock Using Seismic Refraction Unit 2. The following steps may be done on any Windows-based computer.

0. **Have raw data available**

   During data acquisition, you should have chosen the directory where raw data would be saved. Be sure to download all files related to your data collection from the field computer onto the cloud or a USB drive before returning the field computer to the owner.

1. **Download the Pickwin software** (any Windows PC)
   a. Download *SeisImager/2D* using the Download Software button at the web page www.geometrics.com/software. Be sure to note down the location where the program is saved. (The default location seems to be: C: > Program Files (x86) > SeisImager)
      i. The demonstration version may be launched 15 times maximum
   b. If no registration is detected, SeisImager Registration will appear.
   c. If you are using the software on a trial basis without a registration ID or password, click Exit to close SeisImager Registration. When you launch the Pickwin module, the number of runtimes available will be reported; click OK and continue to use the software in demo mode.

2. **Load your measured data**
   a. Launch the Pickwin software module installed in step 1.
   b. Go to: File > Open Waveform Data

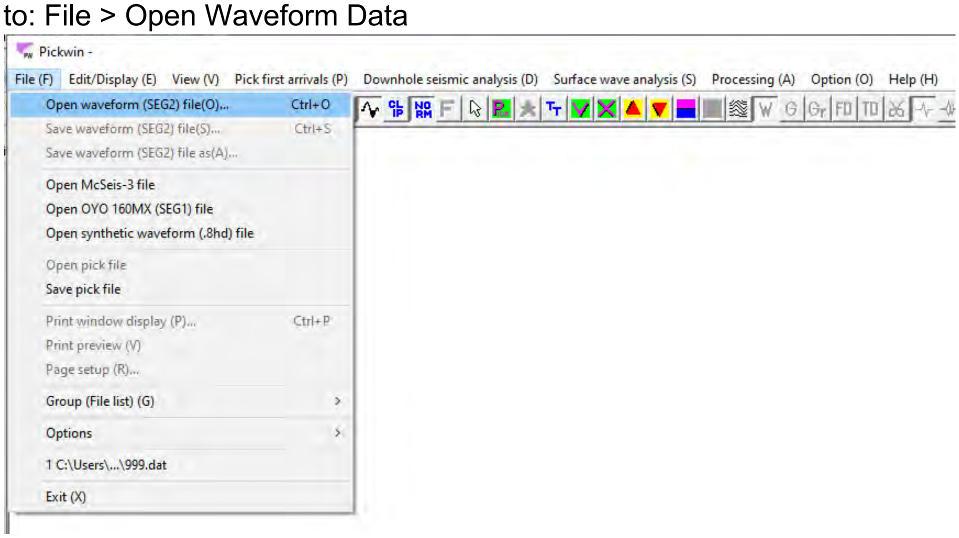


Figure 1

   c. Navigate to the directory where your raw data is stored and select one of the "*.dat" files and press "Open."

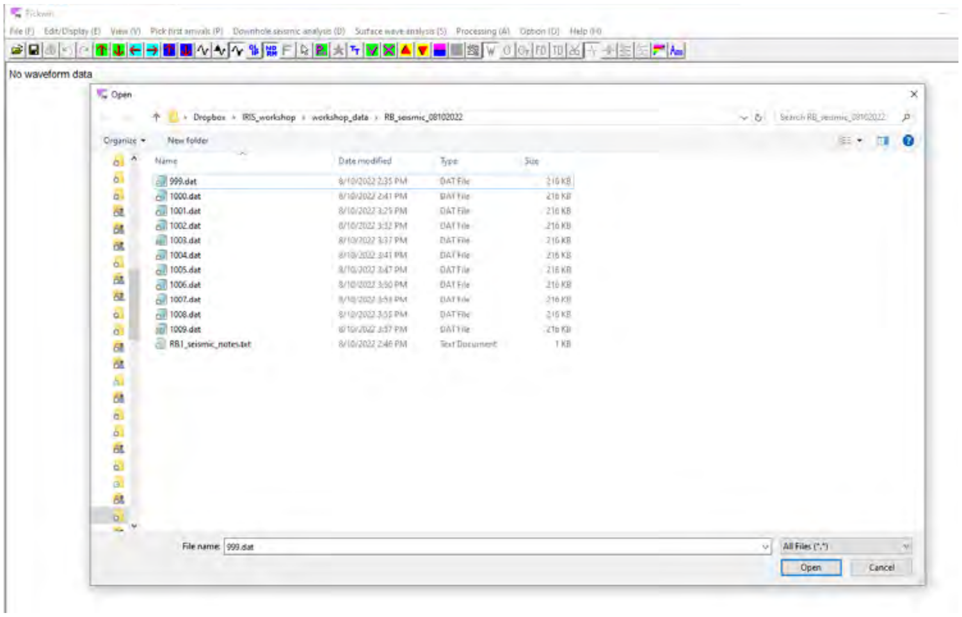


Figure 2

d. A window should display a summary of the dataset. Press "OK."
e. Now, you should see the raw waveform data, though the data will likely be squished into the corner of the window and difficult to see. Next, we will work on improving the display of the data.

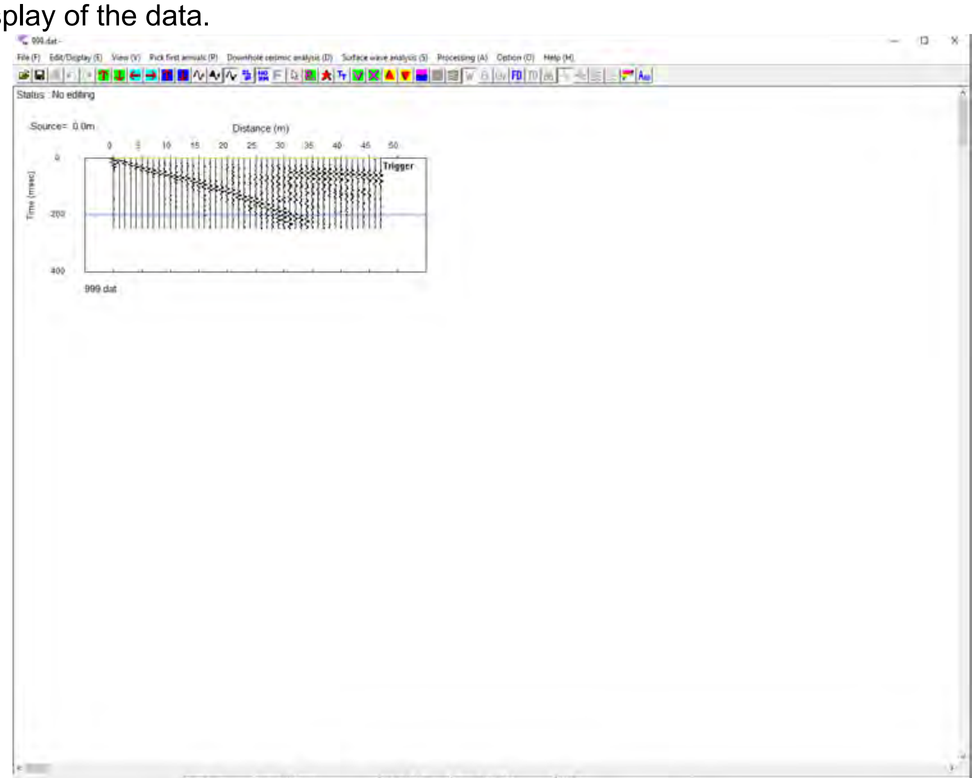


Figure 3

3. Adjust data display settings

a. On the top menu bar of Pickwin, there are three colored pairs of arrows.

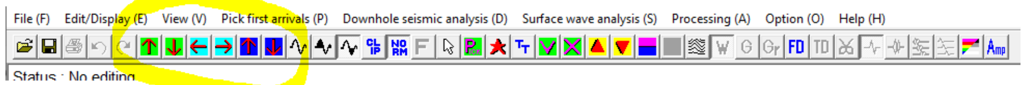


Figure 4

Green arrows: Increase/decrease waveform amplitude
Cyan arrows: Expand the scale in the X-direction (zoom in lateral)
Blue arrows: Expand the scale in the Y-direction (zoom in vertical)

b. Each dataset will have slightly different dimensions, so the exact manipulation here will vary, but start out by pressing the right-pointing cyan arrow 2 or 3 times, and the up-pointing blue arrow 2 or 3 times. Now, your window should look something like this:

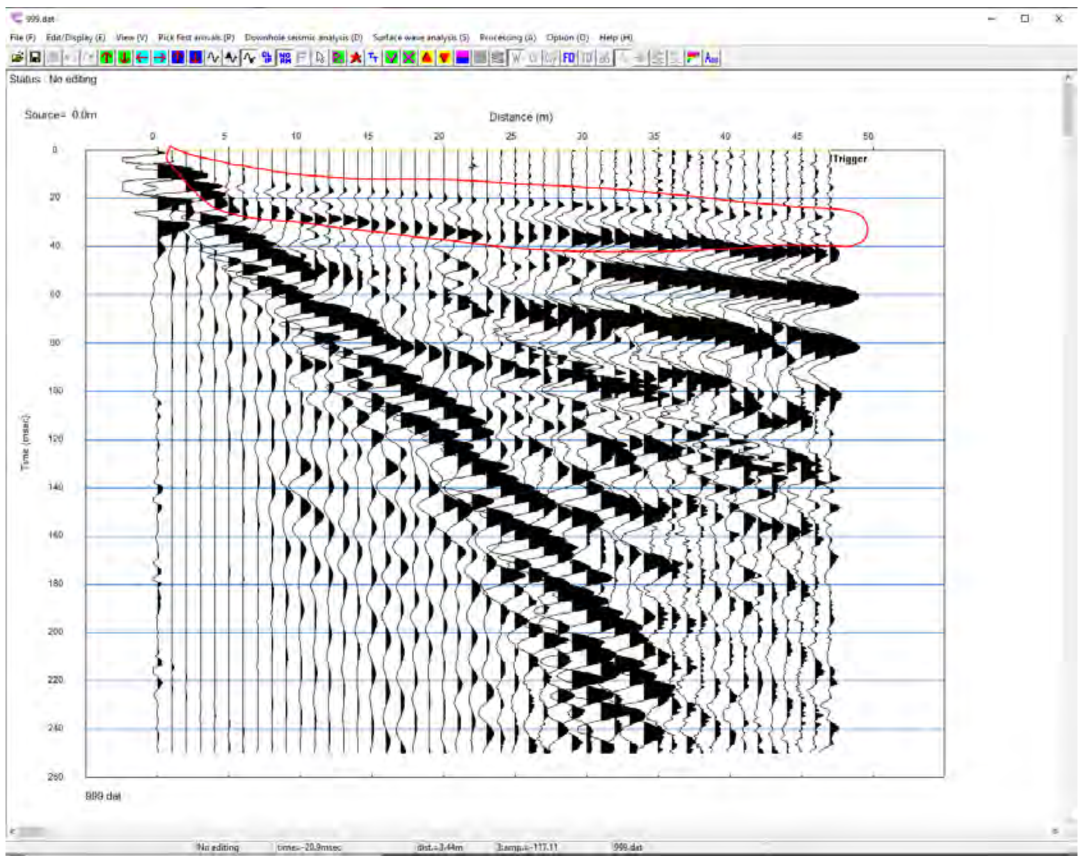
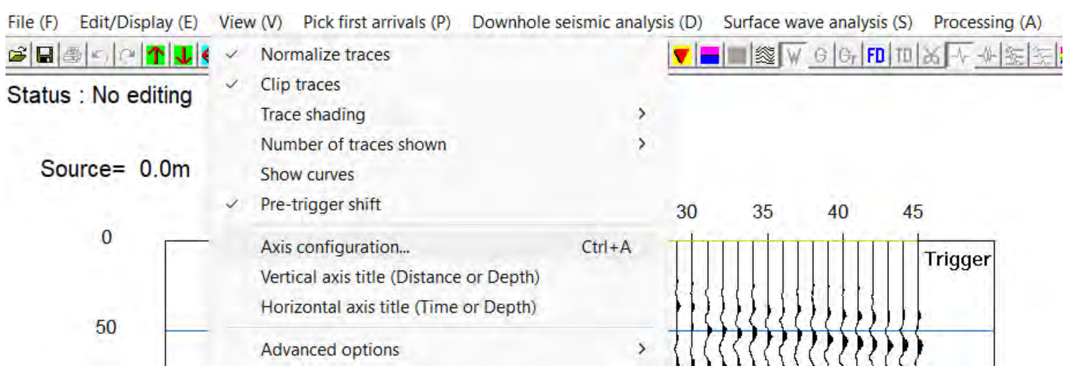


Figure 5

NOTE: If the negative amplitudes of your traces are not shaded black, you can click the circled icon in the top menu bar.

NOTE: Your figure may have distance in the vertical axis and time in the horizontal axis. You can change the axes by navigating to the View>Axis configuration.



In the window that appears, select “Time axis vertical” under the section “Time axis direction” and click OK.

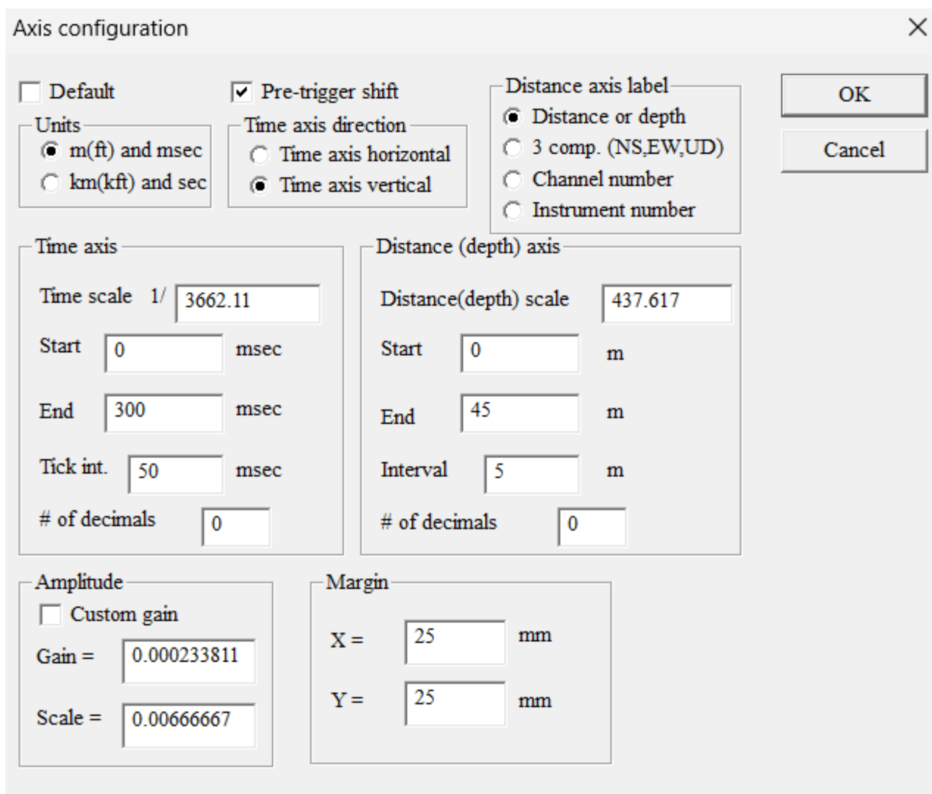


Figure 6

You may need to adjust the scale to view the whole dataset again.
Now, your display should look more like the display in Figure 5 on the previous page. We can see the whole dataset now, but the refraction signal we want is just in the area encircled by red, within the first ~40 msec. So, press the up-

pointing blue arrow a few more times until the maximum time on the Y-axis is about 80 ms (this may vary depending on your dataset).

c. You should now have a display that looks like the display below in Figure 7 with the refraction first arrivals clearly following a linear trend dipping to the right (this will vary depending on the shot point of the dataset you chose. In this case, the shot point is at geophone 1).

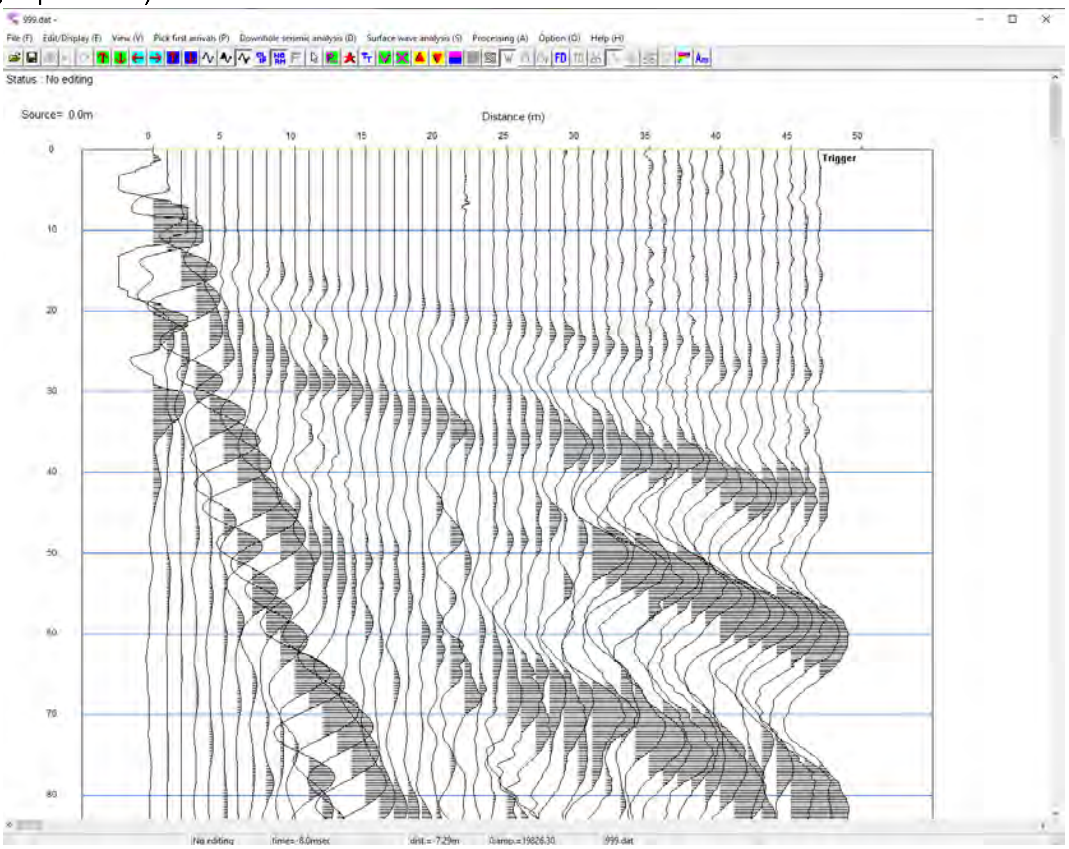


Figure 7

d. Use the green arrows to adjust the amplitude of the traces so that the first arrival wiggles are clearly visible, particularly in the middle of the dataset. Near the shot location (0 m in the image below), the amplitudes of the traces are very large so they obscure the information on the nearby traces—we will fix this next. Inside the blue outlined area on the image below, you can see that the ambient noise is amplified as you amplify the signal in the traces. There is nothing we can do about this, but it won't impact our analysis too much. Just know to ignore the "random" noise in this area of the seismogram.

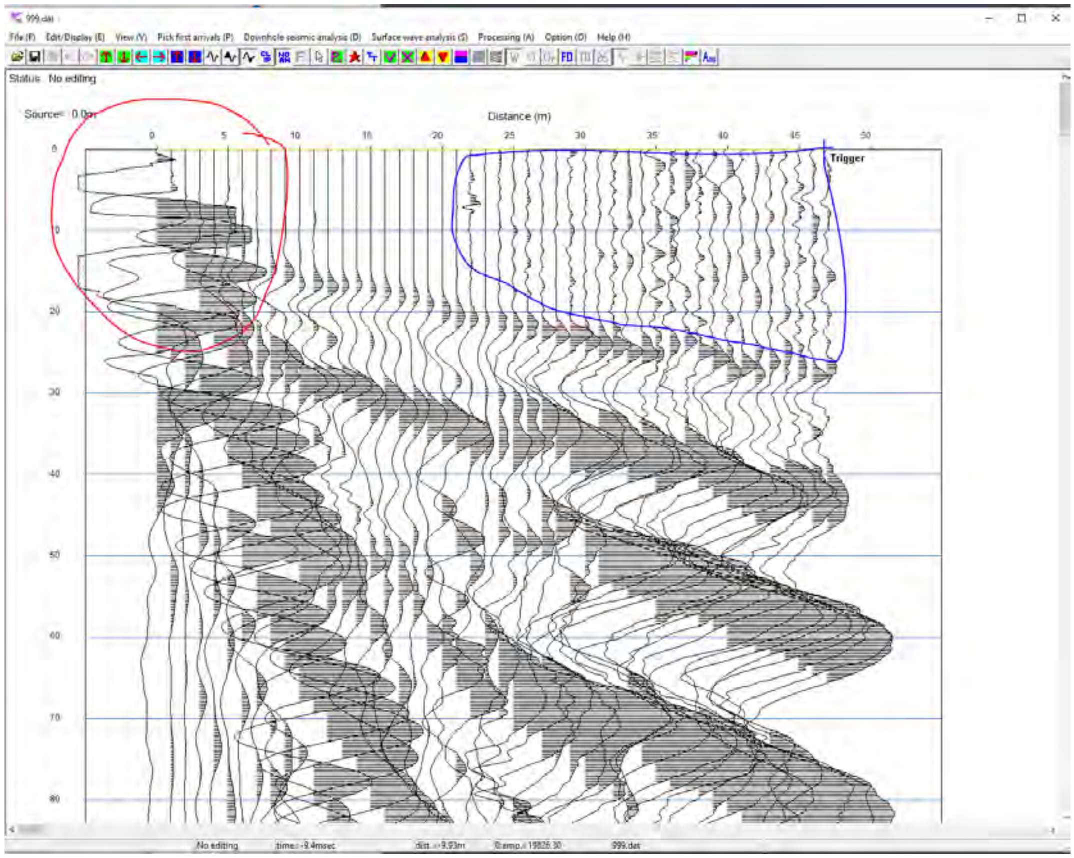


Figure 8

e. To address the high amplitude traces that obscure low amplitude traces, go to View > Clip Traces in the menu bar:

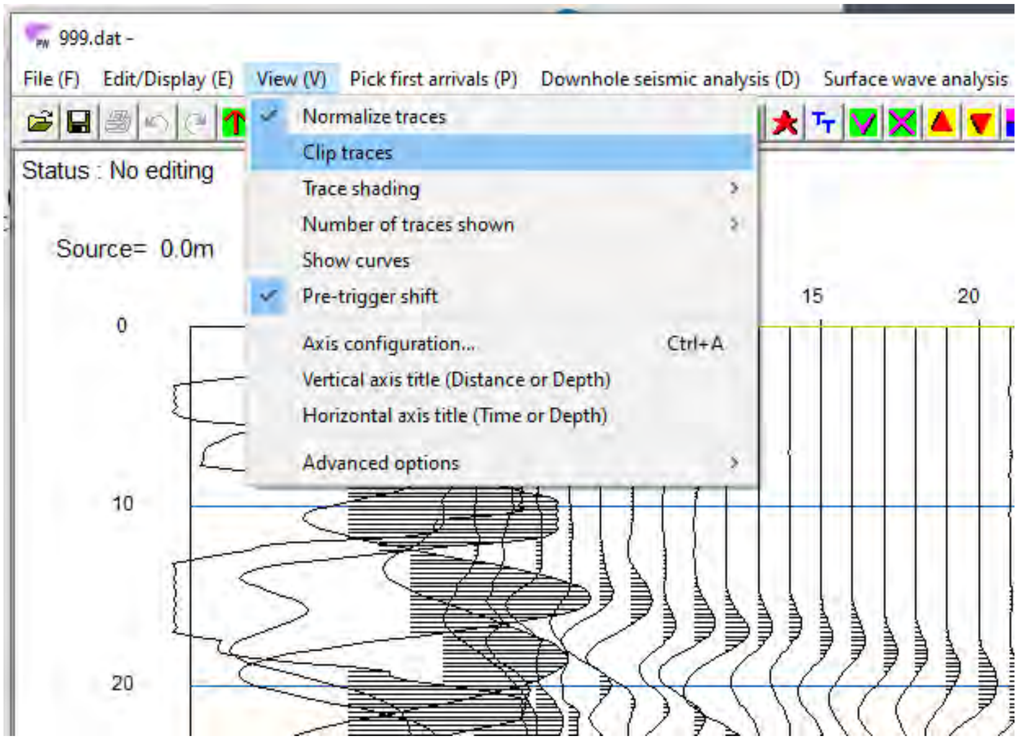


Figure 9

f. And the result will look like this:

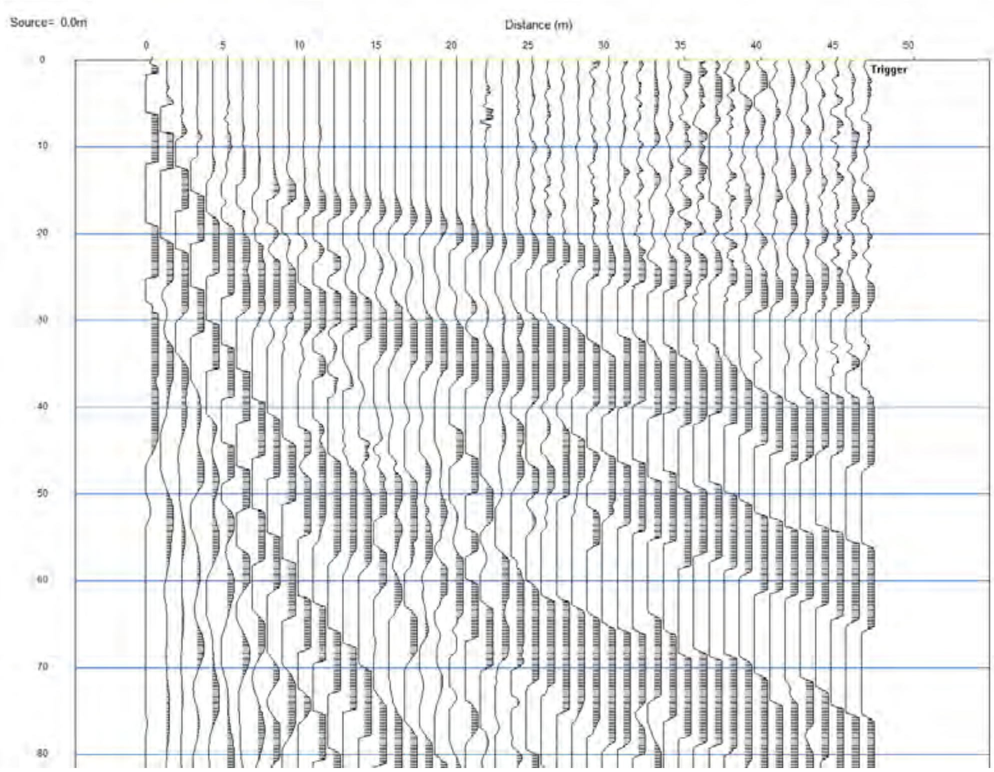


Figure 10

g. Now, you may go back to adjusting the green arrows to make the waveforms around the first arrivals as clear as possible. For example:

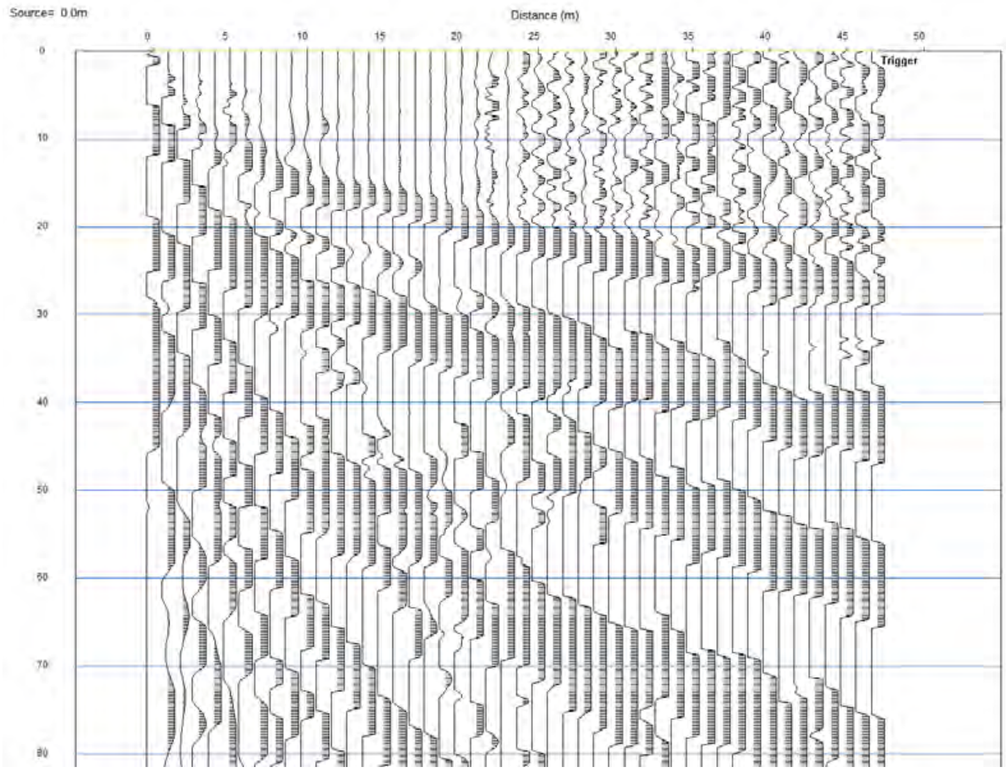


Figure 11

4. Analysis

a. At this point, you can save an image or print the seismogram to provide to students for manual picking (picking = digitizing the travel time-offset data points)
b. Alternatively, you can use the Pick First Arrivals > Pick First Breaks Manually tool in the menu bar. TEACHING TIP: You can do this for the students, or you could ask them to use Pickwin software themselves and follow this guide.

Once you have selected Pick First Breaks Manually, simply use the mouse to click on the image where you see the first change in waveform amplitude along each trace. Here is an example of the picked arrivals.

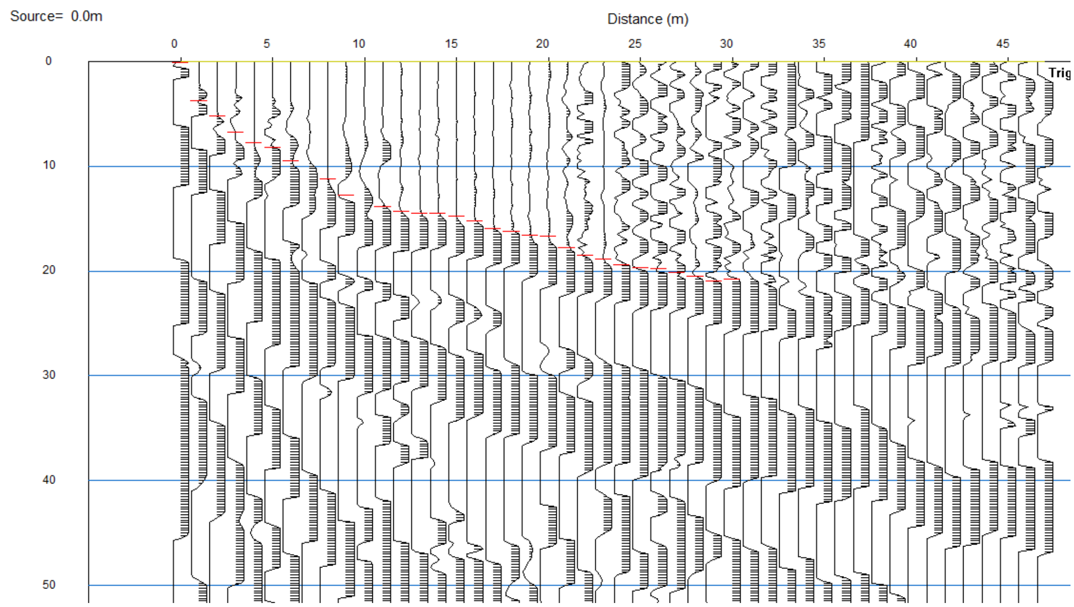


Figure 12

c. <u>CLASS DISCUSSION TOPIC</u>: There is a lot of judgment in seismic interpretation. Sometimes the waveforms will not be totally clean, but you can get a sense for which is the right place to pick based on the adjacent traces. Also, you can see that on the right side of the image where the noise starts to encroach on the data, I stopped picking because it got too hard to distinguish between signal and noise. This is fine for our purposes where we just want to calculate a 2-layer velocity model. To save these picks, go to File > Save Pick File.

d. One way to make it more clear which parts of the seismogram to pick is to draw lines on the image that might represent refractions from different layers. If possible, it is best to have each refraction arrival line defined by at least 4 traces. Here are examples of two ways that this dataset might be interpreted:

Three Layer Structure:

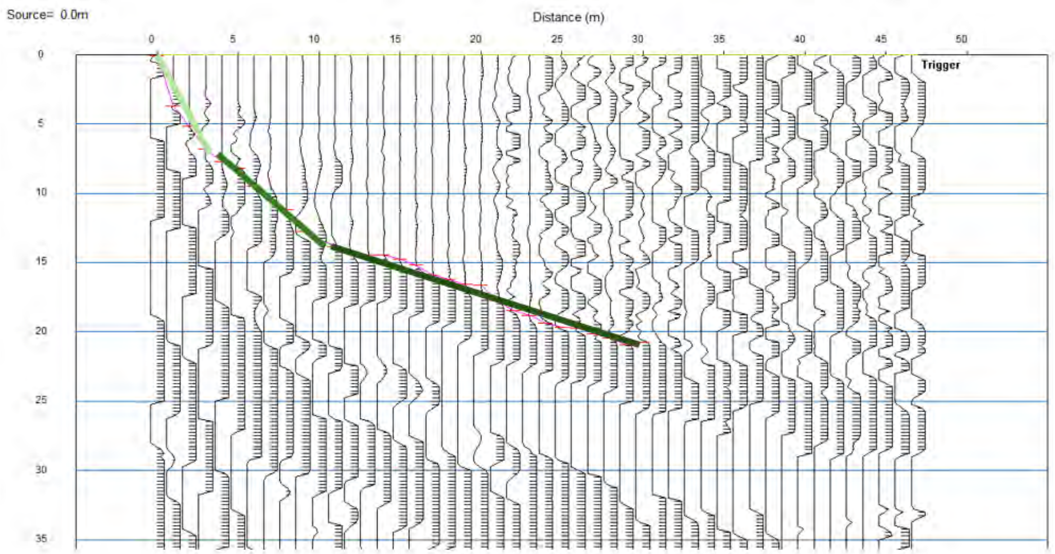


Figure 13

Two Layer Structure:

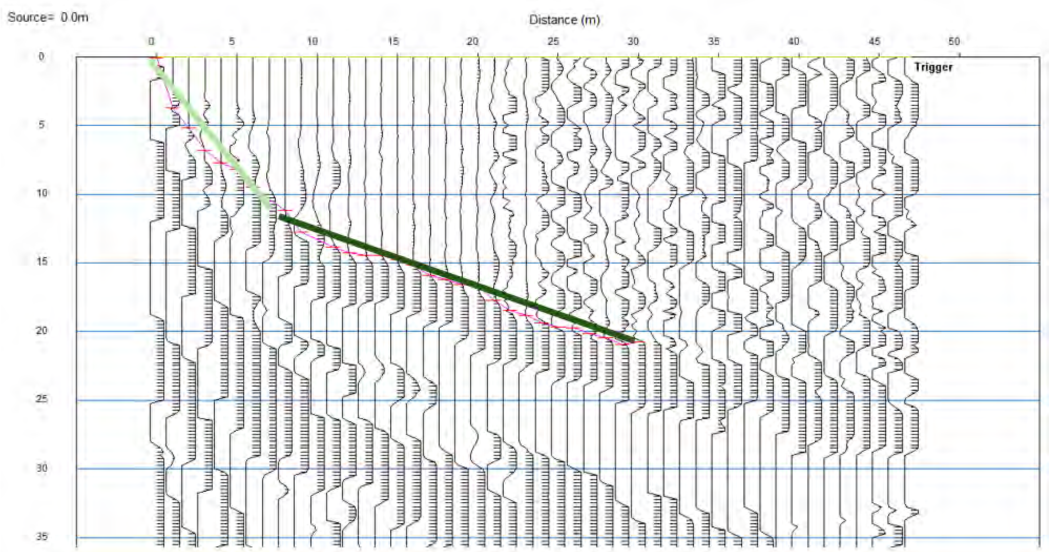


Figure 14

When interpreting the data, we need to have a conceptual model in mind for what structure we will try to recover. In some cases, there may be outside data (e.g., boreholes) that could directly tell us if a 2-layer or 3-layer case is most appropriate. Otherwise, we need to make this judgment based on the data alone. Generally, we want to choose the simplest possible structure that appears to be appropriate for the data. Specifically, we want to identify the locations of sharp changes in the slope of the first arrivals that might indicate refraction to progressively faster velocity layers as we go deeper. In this example data, you can see that the change in slope as you move toward larger distances is gradual—sharp changes are not easy to identify. This is not uncommon and often occurs when the geology transitions gradually between layers. Nonetheless, for our analysis approach to work, we must define layers. As you can see by the thick lines overlaid on the seismogram for the 3-layer case, this seems to do a pretty good job of falling along the first arrival threshold. In contrast, the thick lines drawn on the 2-layer case don't seem to fall right on the threshold of first arrivals quite as well. However, 2 layers is simpler than 3 layers, so that might make the simpler option more desirable. (The thick lines shown are purely a visual approximation—you may choose to shift the locations of these lines however you want for your dataset).

e. Example: Shot in the middle of the line

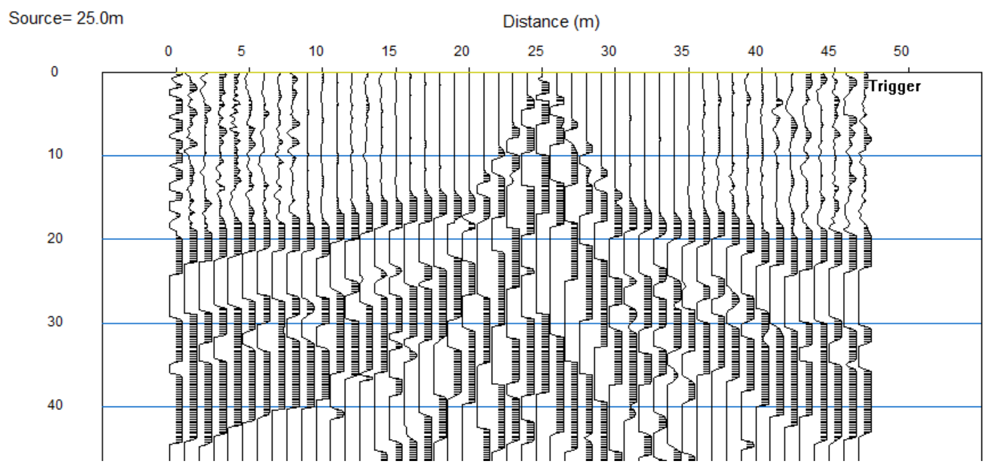


Figure 15

In this raw seismogram, you can see that the shot/source location is at 25 m because this is where the first arrivals are closest to 0 ms travel time. Since we have geophones on both sides of the shot, we get two refraction arrivals that we can analyze. In this image you can see that the change in slope is much sharper than in the previous demonstration dataset and this confirms that it would be most appropriate to use a 2-layer model.

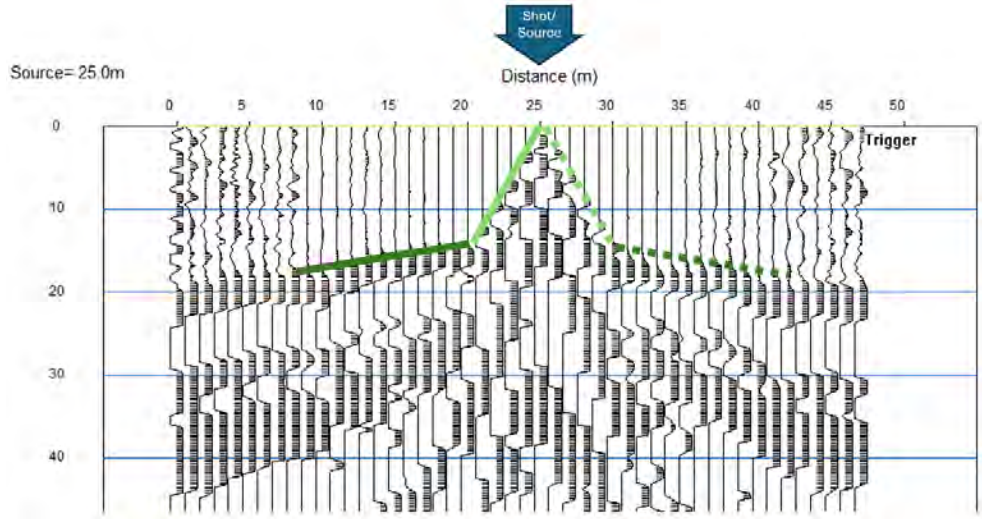


Figure 16

Here is the same raw seismogram as above, but with the two refraction arrivals highlighted with thick lines. In a case like this, the solid line refractions should be analyzed separately from the dashed line refractions, but both may be used to estimate velocity and layer thickness.

f. Example: Shot on the far end of the line

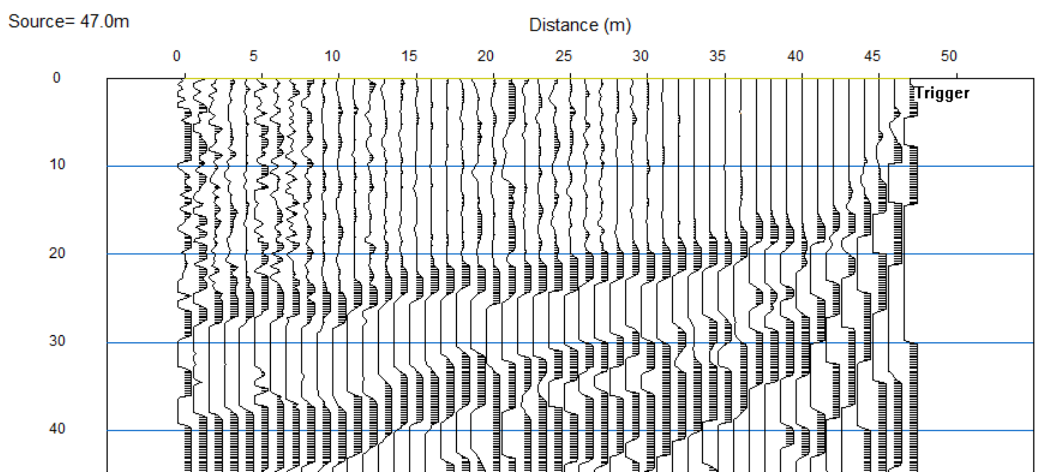


Figure 17

Here is an example where the shot point is at the far end of the line from the seismograph. This looks just like the example used above, except in this image the change in slope of the first arrivals is much sharper.

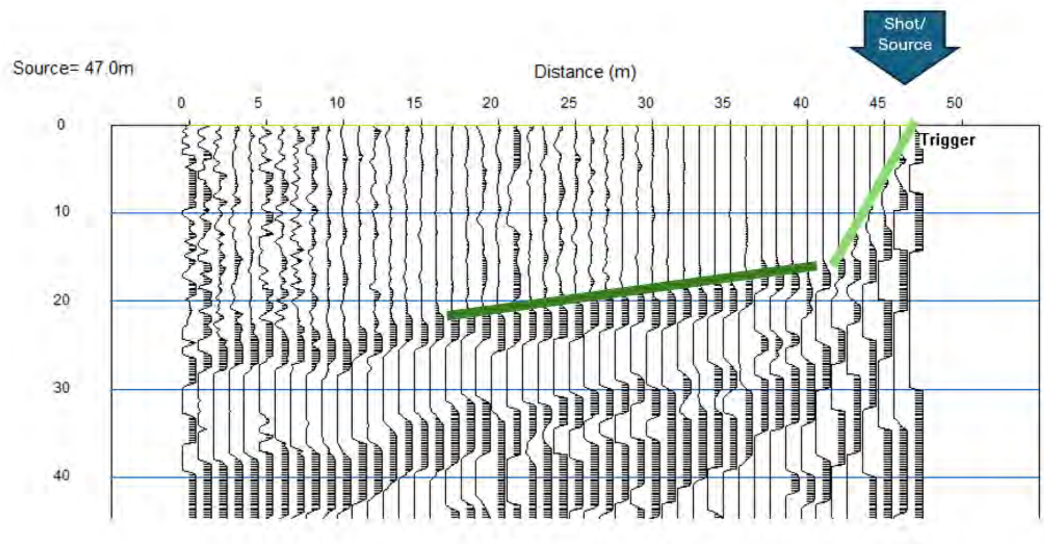
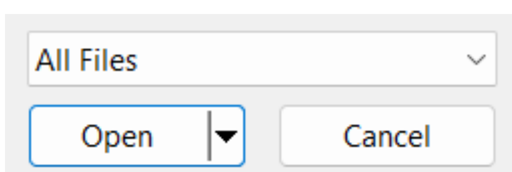


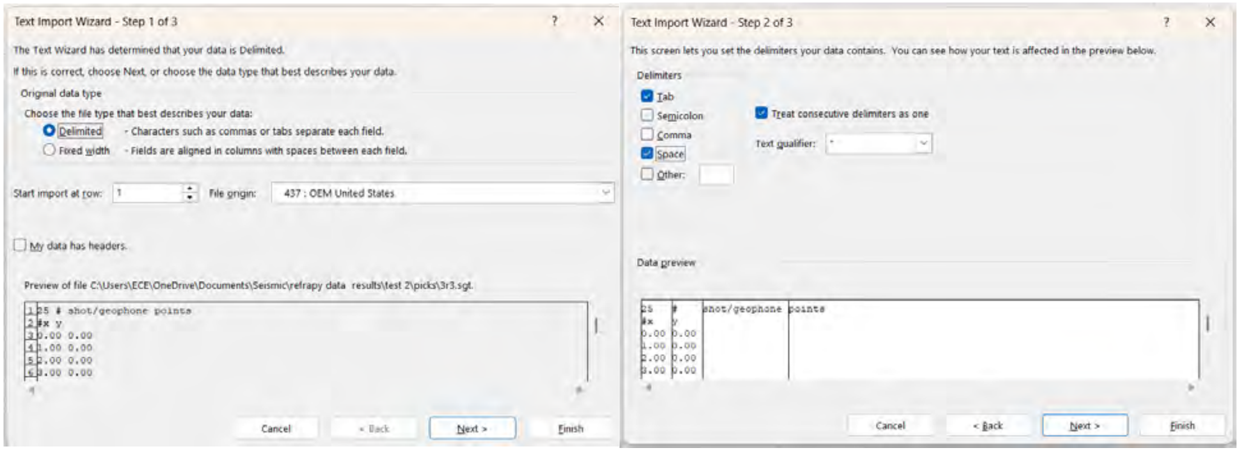
Figure 18

Here are annotated lines illustrating that a 2-layer model is appropriate in this case. This data can be analyzed the same way as the example dataset, but the x-direction values should be reversed so the shot is at 0 and the geophones are increasing positive values.

<u>TEACHING TIP</u>: If you are discussing data quality, errors, and/or uncertainty in your classroom, a good point of discussion is how different people will pick a given dataset and how each set of picks will result in a slightly different set of velocity/thickness results. This can be turned into a synthesis exercise by calculating summary statistics (mean, median, standard deviation) based on the thickness/velocity results from several students or groups within the class.
excel

5. **Saving Data and Working in Excel**
   - **a.** To save the distance and time data for your picks, go to Files -> Save Pick File. This will save the data in a .vs file
   - **b.** To open this file type in excel:
     - **i.** Open excel, select File -> Open. In the browser, make sure you choose All Files instead of All Excel Files in order to see the .vs files. Select your file.
     - **ii.** In the Text Import Wizard pop up, on page one, make sure Delimited is checked and then hit Next.
     - **iii.** On page two, make sure Space is checked, the select Finish.





c. Once in Excel, your data should look similar to the example below. The first two lines and the third column can be ignored. The red box, in this example column A row 3, is the position of the shot. The blue boxes contain the positions of the geophones (column A) and the arrival times (column B) for the picks. This data can be used to replicate the excel exercises in the module or used with your own analysis method.

	A	B	C
1	1996	12	3
2	0	1	2
3	13.5	24	0
4	0	19.75	1
5	1	18.5	1
6	2	18	1
7	3	17	1
8	4	16.4092	1
9	5	16.5273	1
10	6	14.2843	1
11	7	11.5691	1
12	8	8	1
13	9	6.84701	1
14	10	6.49286	1
15	11	4.36792	1
16	12	1.75	1
17	13	0.47221	1
18	14	0.47221	1
19	15	3.5	1
20	16	4.36792	1
21	17	7.31922	1
22	18	10.1525	1
23	19	12.6316	1
24	20	15.5829	1
25	21	16.9995	1
26	22	18.18	1
27	23	20.0688	1
28	0	0	
29		0	
30		0	0
31			

6. Connection to GETSI curricular materials

The "2-layer seismic refraction exercise" XLSX workbook provided in the Seismic Refraction Unit 2 can be either used directly or adapted to analyze the travel time-offset data extracted from the raw seismograms.
https://serc.carleton.edu/iguana/teaching_materials/seismic/unit2.html

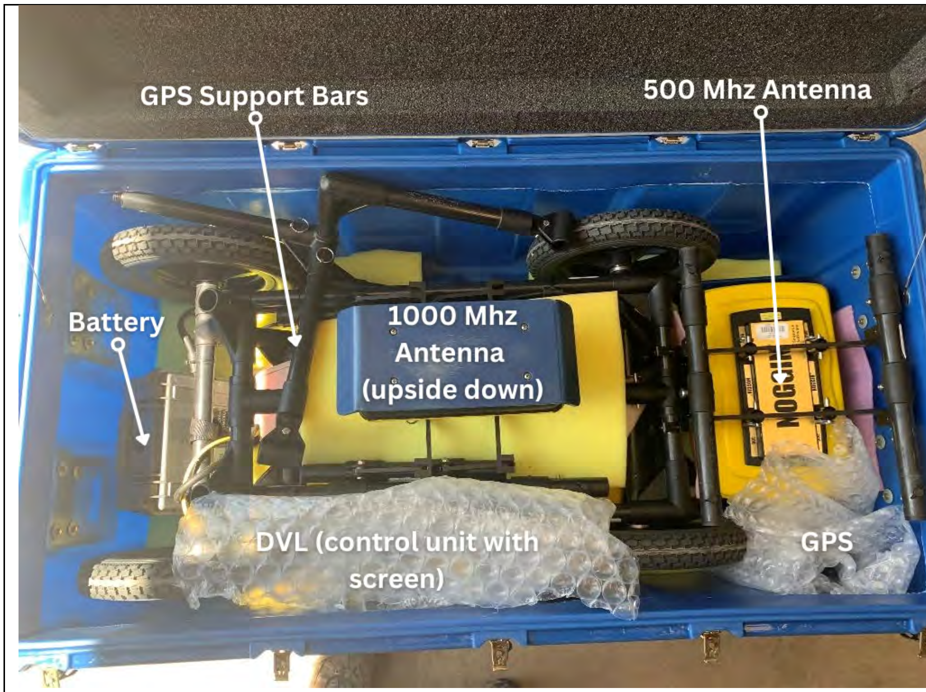
EarthScope Noggin GPR Packing and Assembly Guide

Sarah Kruse (University of South Florida)

Introduction

Assembly instructions are documented in the manual. The photographs here show unpacking and assembly instructions specifically for the EarthScope cart configuration. The photos can be used in reverse to repack the components. This photo shows assembly with a short version of the horizontal bar that holds the GPS, which made the GPS tilt slightly toward the rear of the cart. There is a separate longer bar that should be used with the 500 MHz antennas.

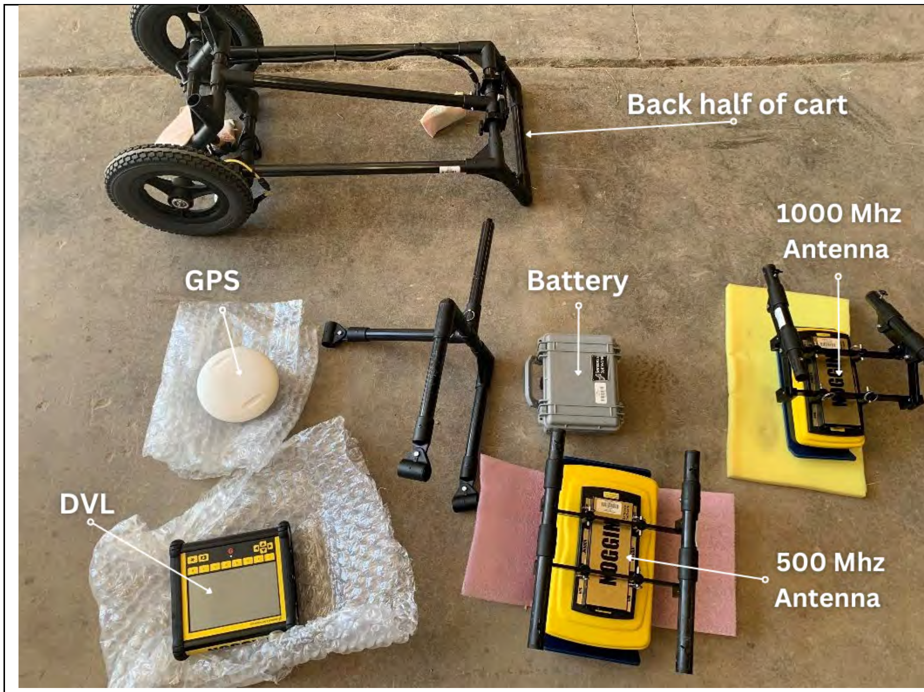
Components Overview

	Fully packed, all components labeled
 	DVL (digital video logger; i.e. "screen") and GPS

Step 1: Unpacking

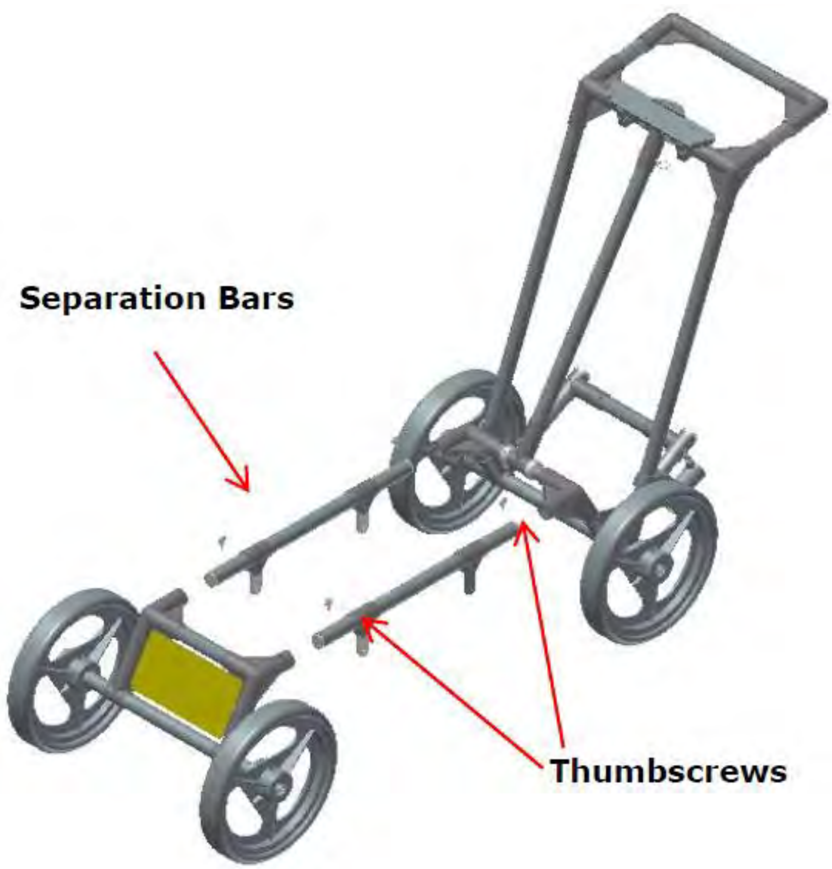
	a) Remove DVL, GPS, and GPS support bars.
	b) Remove battery and 500 MHz antenna

	c) Remove 1000 MHz antenna. Pink bags are connector covers.
	d) Remove back half of cart (which contains odometer). This leaves the cart front wheels and the 250 MHz antenna in the shipping box.

	Components that have been unpacked: ● back half of cart ● GPS ● GPS support bars ● Battery ● 1000 MHz antenna (smallest) ● DVL (control unit with screen) ● 500 MHz antenna (bigger)

Step 2: Assembling the Cart and Antenna

	a) To assemble cart, start with the back half.



b) Attach antenna of choice (500 MHz shown here).

Note: When shipped from Earth Scope, the antennas will be attached to the separation bars. Be careful with the thumbscrews – they will stick after half a turn if they are not aligned properly. If they stick, back out and start over.

	c) Attach front wheels.

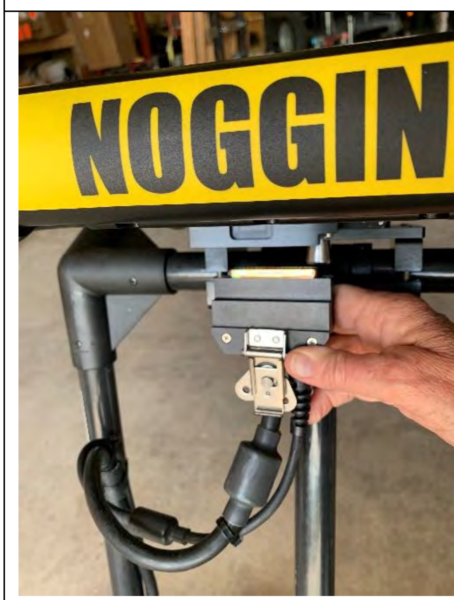
Step 3: Attaching the DVL (Digital Video Logger)

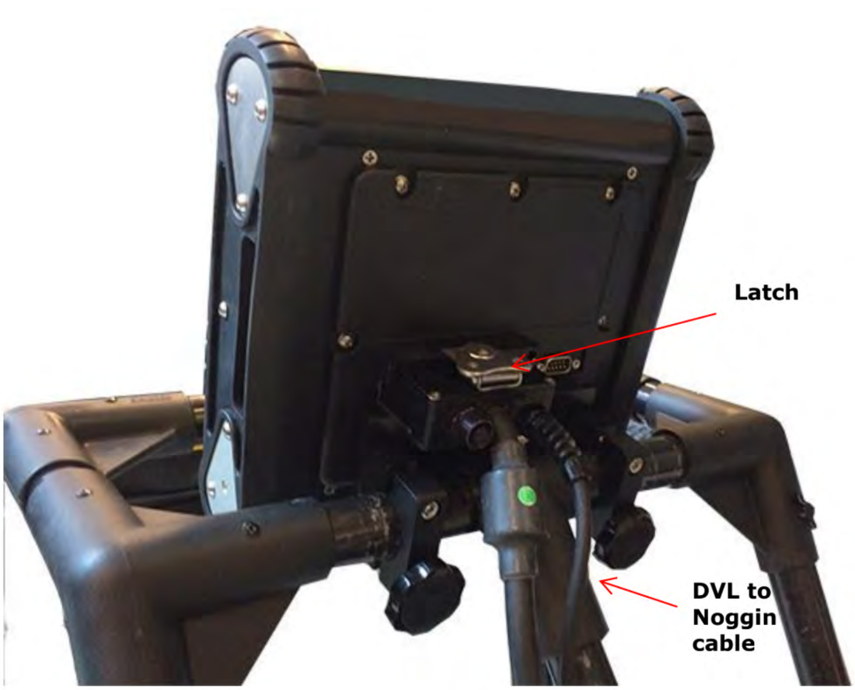
	a) Align the back plate on the DVL with the mount near the cart handle. b) Slide the DVL onto the mount so that the sides of the mount catch on the DVL back plate. c) The release pin will snap into place when secure. Tip: Wiggle the DVL to make sure it is firmly connected before letting go of the DVL unit.

	d) Pivot the DVL to adjust the view angle. Tip: Adjust the thumbscrews on the bottom of the support shelf as needed to help with adjustment.

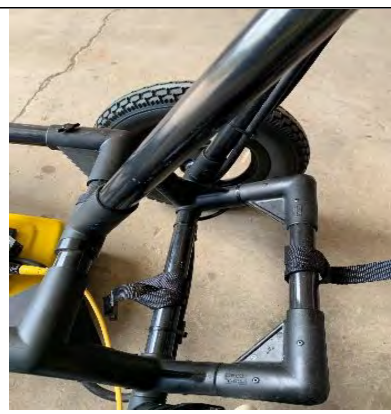
Step 4: Connecting the Antenna and DVL

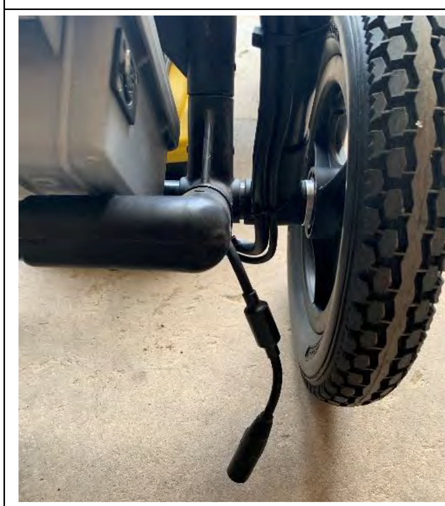
	a) **Gently** connect the 37-pin Connector into the back of the antenna. Tip: Be sure to connect *gently and carefully!*

	b) Once you are sure it is properly seated, then flip the latch.
 	c) Squat underneath the DVL (screen) and **gently** connect to the cable coming off the top of the cart. Tip: Don’t try to do this from above without looking at what you are doing.

 	d) Secure the connector cable with the latch. Tip: Don't turn the latch until you are sure you have the connector seated properly.

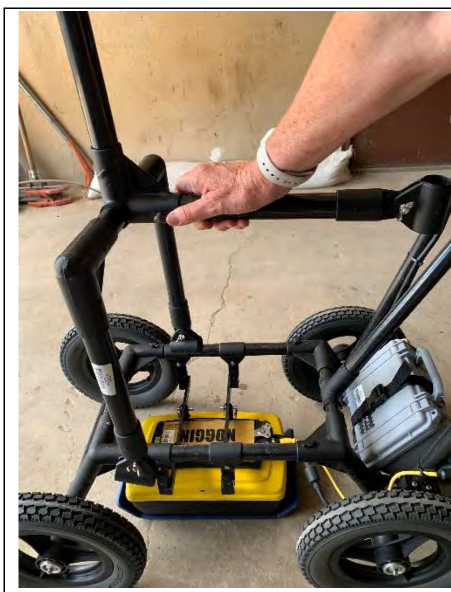
Step 5: Attaching and Connecting the Battery

 	a) Unfasten the strap on the lower rear of the cart. placing battery as shown, and refastening the strap.

	b) Place the battery onto the lower shelf on the back of the cart. Tip: Make sure the handle on the battery pack is facing the back of the cart and that the battery is somewhat secure on its shelf.
	c) Refasten the strap around the battery pack
 	d) Connect the battery to the connector on the lower right on the cart.

	Now everything is connected except the GPS. Note: The GPS should be mounted above the mid-point of the antenna. The 500 and 250 MHz antennas have the same GPS post. If you are using a 100 or 1000 MHz antenna, you will be provided with a different post for those.

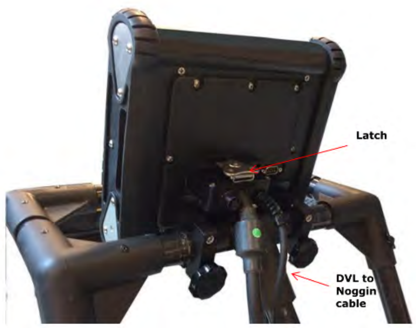
Step 6: Attaching and Connecting the GPS

 	a) Open two tube clips and push them over the separation bars. Position the clips at the mid-point of the Noggin antenna.

	b) Use two screws with a lock washer and wing nut to fasten the U-shaped vertical support section onto the tube clips on the separation bars. Tip: It helps to have two people for opening the wingnuts, getting all three connection points in position, and tightening the wingnuts.
	c) Carefully screw in the GPS on the vertical mounting post. Note: some Noggins may have a GPS unit that looks a little different than the one in these pictures

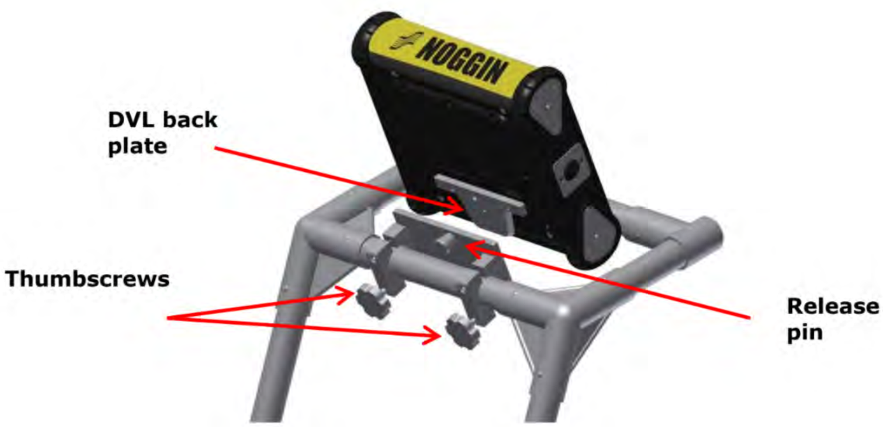
	d) Connect your GPS to the DVL. The cable sends data to the DVL. If your GPS is Emlid brand, you will need to charge the GPS unit separately. With other brands, the GPS may be powered by the cable. Tip: Make sure the DVL is powered down when connecting or disconnecting the GPS cable.
	What the four different GPR antenna look like. They can all be fit to the Noggin SmartCart.

Step 7: Disassembling



a) Power down and unplug all powered parts.
   1. Disconnect GPS from DVL.
   2. The DVL from the 37-pin connector cable.
   3. The battery from the battery connector.
   4. The antenna from the 37-pin connector cable.

Be particularly **gentle** with the 37-pin connectors.

	b) Unscrew the GPS unit from the supports. Tip: set the GPS unit (along with the DVL, battery pack and cables) to the side in a safe place, but don't put them back in the box just yet. There is a specific packing sequence we will outline below.
	c) Remove the DVL.

 	d) Release the strap and remove the battery pack.
	e) Detach GPS Vertical Support system 1. Release the quick release pin and remove the top mounting post. 2. Unpin the horizontal support bar from the vertical support section. 3. Unscrew the tube clips beneath the U-shaped vertical support section and remove it from the clips. 4. Remove the tube clips from the separation bars.

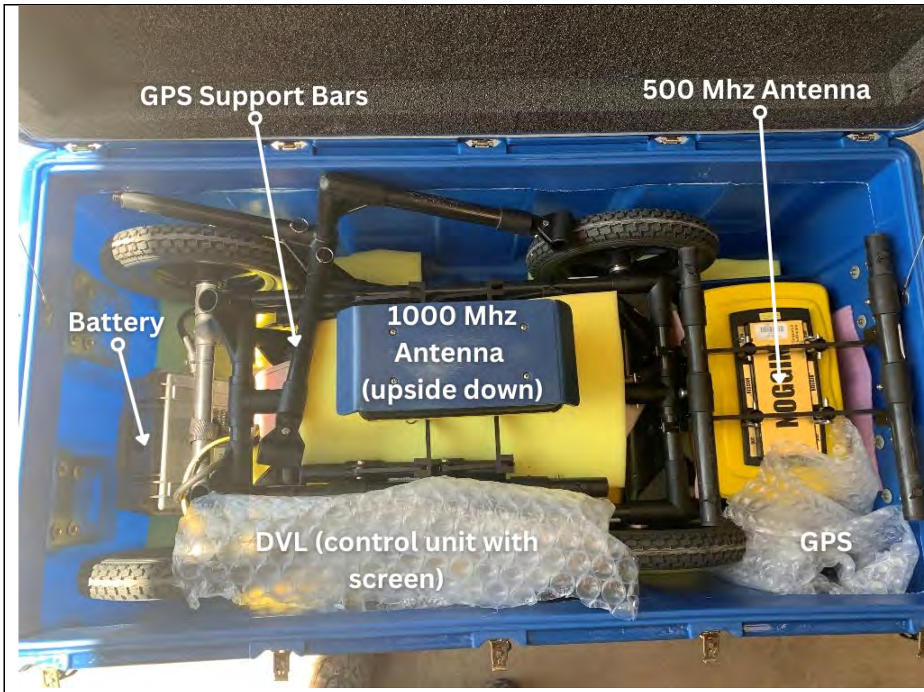
f) Disassemble the cart
   1. Remove the front wheels.
   2. Unscrew and detach the separation bars from the back half of the cart.

   Tip: keep the antenna attached to the separation bars

Step 8: Packing Up

a) Insert the 250 MHz antenna and the cart front wheels in the shipping box.

	b) Insert the 1000 MHz and the back half of the cart into the shipping box.
	c) Pack the battery pack on one edge of the shipping box. Pack the 500 MHz antenna on the other side of the box.



d) Pack the GPS support bars towards the back of the shipping box, overlapping the 1000 Mhz antenna.
e) Rewrap the DVL and pack it below the 1000 MHz towards the front of the box.
f) Rewrap the GPS unit and pack it below the 500 MHz antenna towards the front of the box.

With that, all components should be packed in the shipping box!

GPR Unit 3: GPR Survey Guide

Sarah Kruse (University of South Florida), Kitri Spencer (EarthScope Consortium)

This document provides a guide to preparing for and conducting GPR surveys. It includes:
1. *Recommended supplies*
2. *Selecting a survey type*
3. *Things to do before the main data acquisition*
4. *Doing a Line Survey*
5. *Doing a Grid Survey*
6. *Data Acquisition Tips*

Introduction

Almost ready to begin your GPR survey with your students? This document will outline all of the supplies you need, how to select the right survey type for your needs, how to set up your desired survey, and what tips may make your survey proceed smoothly.

1. Recommended supplies

In addition to your GPR Unit and cart setup, here are other items you will need to set up your survey:


- >8 GB USB Drive
- 2 100-m survey tapes
- 8 *plastic* markers or flags
    - For example, Vinyl Marking Flags (https://www.amleo.com/plastic-staff-marking-flags-glo-red/p/45P-1R)
    - Alternatively, plastic tent stakes that are high visibility will also work
- Roll of string, preferably neon-colored or high visibility
    - For example, 250 ft. Nylon Orange Line (https://www.amleo.com/plastic-staff-marking-flags-glo-red/p/45P-1R)

2. Selecting a survey type

Depending on the type of subsurface feature you are looking for, the time you have with your students, and the space available, there may be a survey type best suited for your needs. The two primary survey types are:

- Line Surveys
- Grid Surveys

<u>Line Survey</u>

If you want to be extra careful about the location of your line survey, you may want to set up a line using high-visibility string and a measuring tape.

When to Use
- When you want to do an exploratory survey (scanning)
- When you have a large area to survey
- When you are limited on time to survey

When Not to Use
- When you want to make 2D depth slices
- When you have limited maneuverability
- When you want resolved 3D images of the subsurface
- Don’t do a line survey parallel to a linear target

Grid Survey

The grid survey is considered the traditional method of GPR surveying. You may use the Noggin GPR System to acquire your survey grid, or you may set up a grid using high-visibility string and a measuring tape.

When to Use
- When you want to do a more detailed survey
- When you want to create 2D depth slices or 3D images of the subsurface
- When you have more time to survey
- When you need to detect smaller targets

When Not to Use
- When you have a large area to survey
- When you are limited on time to survey
- When you have rough ground

3. *Things to do before the main data acquisition*

Charge the battery

The GPR Kit from EarthScope should include a grey battery pack shaped like a small suitcase and an adapter to charge that battery pack. The battery pack powers the GPR antenna, Display Video Logger (DVL), GPS unit, etc., so be sure to charge it indoors at least one night prior to the survey date.

- See the Noggin GPR Operation Guide from Sensors and Software for additional information.

Check the weather and your soil suitability

Soil type and moisture will affect how deep you can see with GPR. If you are in soils with very limited depth of penetration, it’s better to try in dry conditions. On a wet day you will see stronger returns from layers in the ground, but you will likely not see as deeply.

- Check your soil suitability using the USDA Ground-Penetrating Radar Soil Suitability maps. If your soils are not suitable for GPR (the GPR signal does not penetrate deeply enough), you can probably still use GPR to find buried pipes or tree roots and could definitely use it to find rebar in concrete or joists in floors, but you may not be able to do deeper soil surveys.

Consider your site

If you pick up nice but shallow hyperbolas (< 1 m) with the 250 MHz antennas during your test survey you may want to re-survey those features with 500 MHz antennas as the hyperbolas may be a bit clearer and you will see more of any other shallow features. Then you can choose the optimal frequency to run with students if you have limited class time. It takes a bit of time to change antennas.

If you want to use the GPS unit, be sure your site is relatively clear of heavy tree cover or tall buildings. These obstructions can interfere with the GPS function. While using the GPS unit is optional, combining your GPR data with GPS can be advantageous when processing your data after the survey, if precise location information would be helpful to your study. For the highest precision location information, you can also set up a GPS base station over a known point so that the rover GPS unit on the GPR can receive location corrections from the base station (see more about GPS surveys: https://serc.carleton.edu/getsi/teaching_materials/high-precision/index.html)

- Tip: Your campus facilities may have maps that outline locations of pipes and other subsurface features. You can reference these maps to select a site and give your students a clear objective with the GPR Survey.
- Tip: Before you head out to a distant field site, you may want to test the GPR instrument closer to home (ex. Line Survey steps 1-6). Also make sure that you GPS rover on the GPR is getting fix (if you have a base station as well).

Test your Site

It is worth doing a preliminary survey before you go out with students. Run some profiles across the area of interest and mark with physical flags in real time the approximate locations of features. It is not worth setting up and acquiring a grid of GPR data unless you know you will find some buried targets.

We recommend starting with the 250 MHz antenna because it will see deeper than 500 or 1000 MHz but has higher resolution than 100 MHz. Set the time window to 30 ns and depth to 2 m to start with. Or estimate a velocity, based on what you know about the substrate. Velocities in soils and bedrock are usually 0.07-0.14 m/ns. The radar wave velocity is lower when the water content is higher.

Move the gain level to a higher value if you are not seeing any returns after the direct wave. Make sure you are seeing the whole time (depth) window on the screen. Zoom out on the Noggin screen if needed.

For tree roots, try going in a rough circle around the tree. Put in a marking flag in the ground at any locations where you see distinct upside-down U's. You can back up the cart and it will show you where you are, and you can try to match the top of the U. It will collect data again going forward. Do a circle with a larger radius to see if you can map roots as they radiate away from the tree. (Note the GPS may not work when you are under the tree canopy, but if you can track roots further out you can record good positions.)

For buried pipes, you can survey parallel to a wall on the outside of a building. Or go in a circle around a light pole.

Determining Site Suitability

If you can make sense of the pattern of the major hyperbolas in your data after you test your site, you can return to the site with students where you know they can get results.

What would your data look like if the GPR signal does not penetrate the ground even to shallow pipes? It might look like the boxed data in Figure 1. You can see that there is a horizontal banding that appears when there are no reflected waves returning to the receiver antenna. This is "system noise". If an initial scan of your site reveals only system noise, select another site with clearer returns for your students.

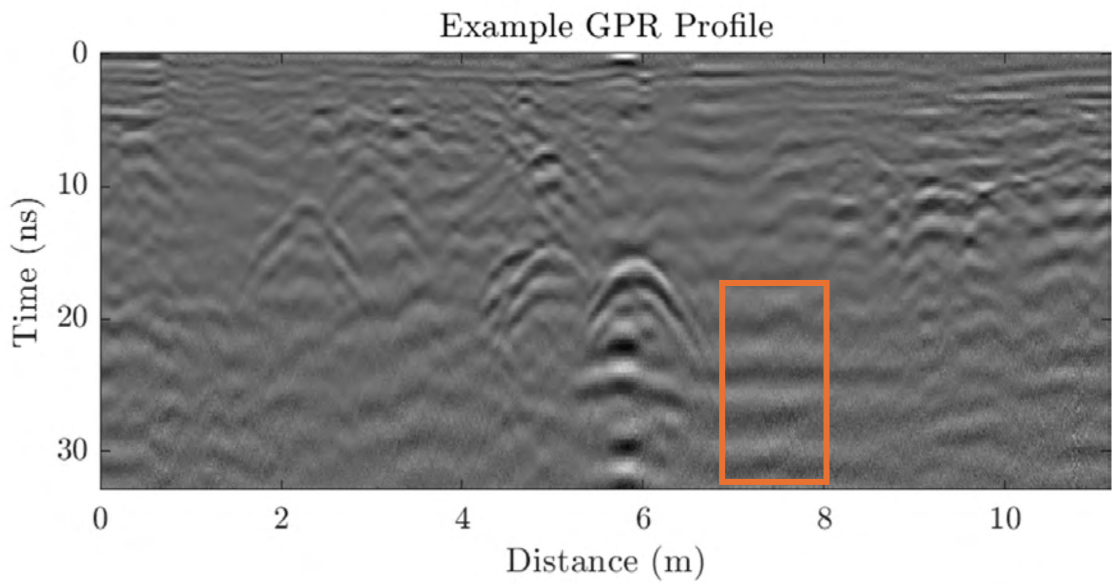


Figure 1: Example GPR Profile with clear returns and system noise.

Optional: Set up your Grid ahead of time

If you are collecting data on a grid, it can take some time to set out the square grid. If you are time-limited and want the students to focus on the data acquisition, you may want to set up the grid yourself ahead of time. Refer to the How to: Grid Survey section of this document for additional information.

- Tip: It helps to have at least two people to set up the grid.

Optional: Calibrate your Odometer Wheel

If you want to calibrate the odometer wheel, you will need to lay out a survey tape or measuring tape for 10 or 20 m and stake the tape down. Calibrating the odometer wheel is not essential – if the wheel moves slightly differently over your surface than expected for the calibration, then your distances will be slightly off, and your velocity and depth calculations will be slightly off, but probably not significantly.

4. Doing a Line Survey

Using the Noggin GPR System

Step 1
Turn on the Digital Video Logger (DVL) and adjust the brightness as needed.

You can swipe down from the top of the screen toward the bottom to see a menu that lets you check the battery level, change the sound level, and change the screen brightness.

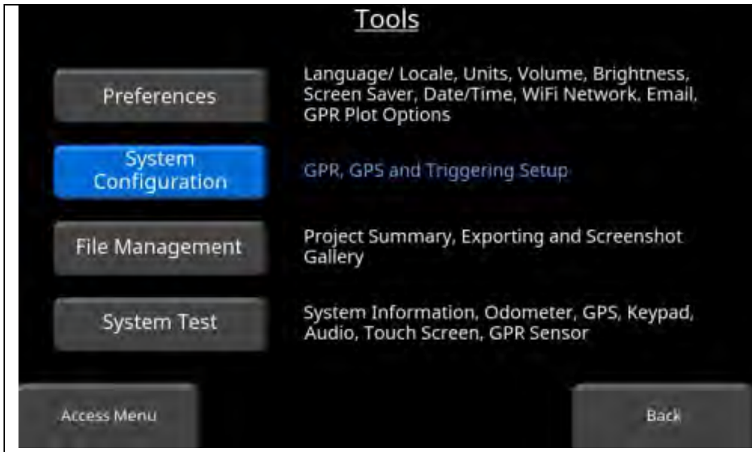
Step 2
Set the GPS Settings. From the main menu, select

- Tools
- System Configuration
- GPS

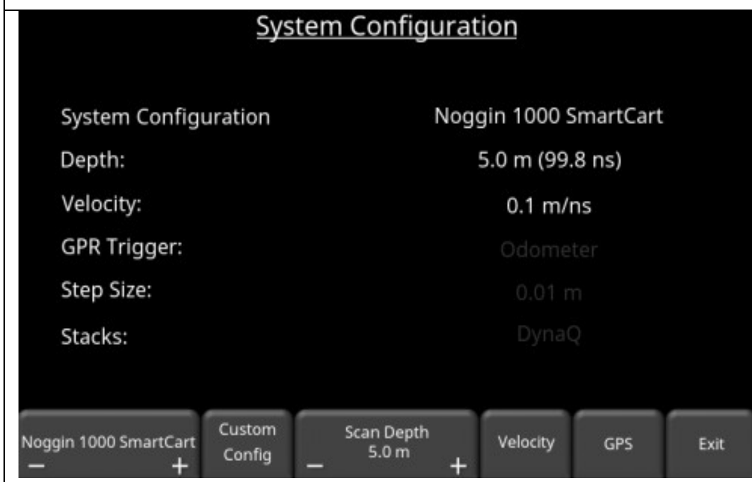
In the **GPS** window, set the following:

- GPS Mode = External
- Topcon or Trimble brand GPS
  - Baud Rate = 19200
  - Serial Port Power = On
- Emlid brand GPS
  - Baud Rate = 9600
  - Serial Port Power = Off

If the system is outside, a small green LED on the GPS indicates that the system can be seen by the GPS satellites and is ready to use.



Tip: The data will be easiest to process if you choose Universal Transverse Mercator (UTM) map projection to map your data.



Step 3
Return to the System Configuration menu and set the System Configuration parameters for your profile.

System Configuration= Noggin Smart Cart

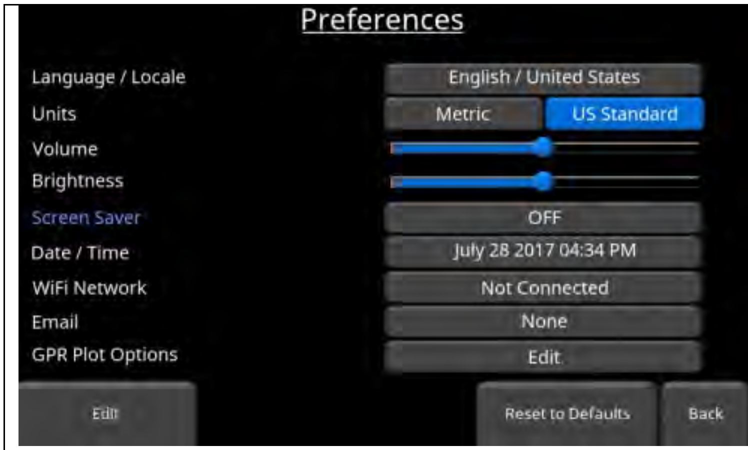
Velocity – set to value expected for your environment. If not sure, choose 0.1 m/ns.

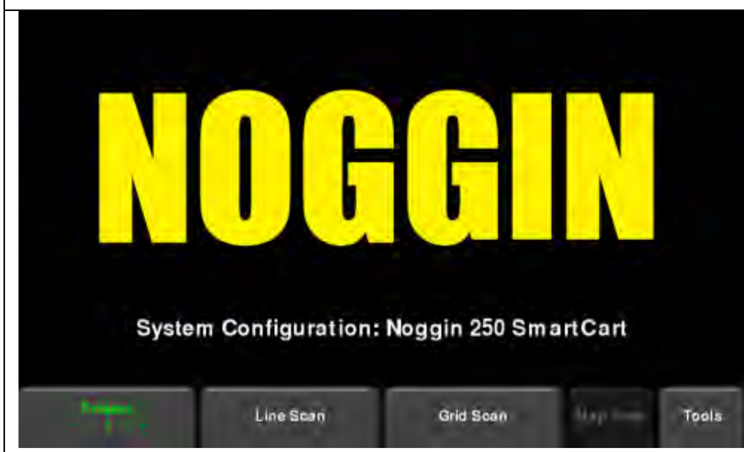
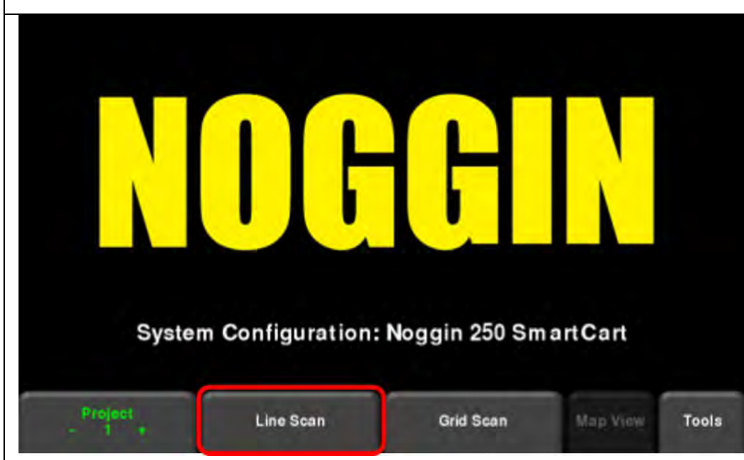
Depth - With your velocity guess, now set the depth to about twice the depth of the deepest target you hope to find. (For buried pipes or tree roots, set to ~4 m.)
Important note – if you zoom in on the depth while collecting data, it will only export data to that depth rather than the one set here.

GPR Trigger = Odometer

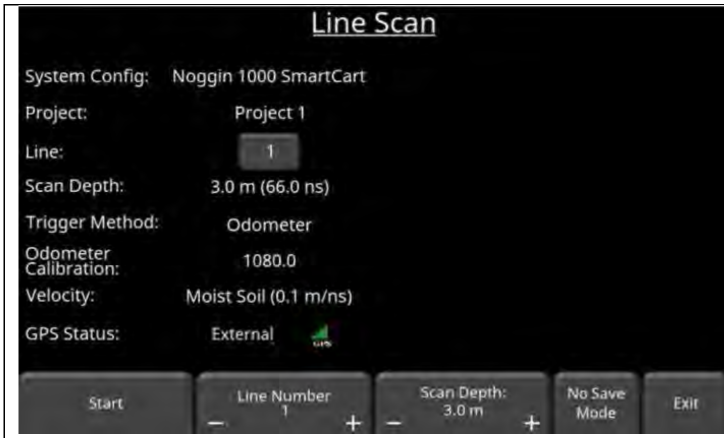
Step Size – use the default value recommended for your antenna frequency

Stacks – set to DynaQ

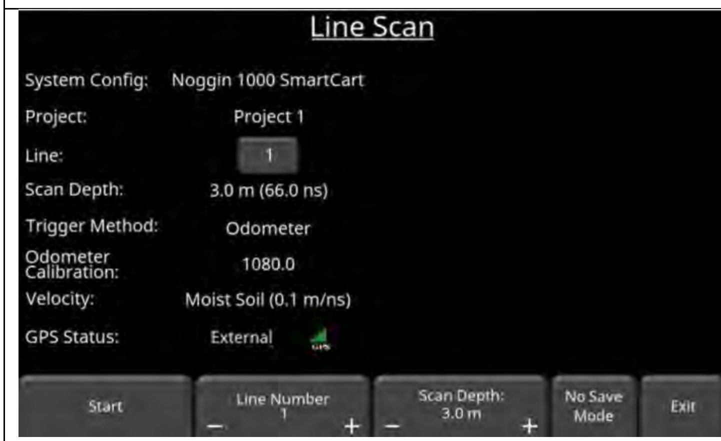
<table>
<tr>
<td>
</td>
<td>Step 4
Return to the Main Menu, choose the Preferences Menu and change the Preferences as needed.

Tip: You do not need to enter a Wifi network or email.</td>
</tr>
<tr>
<td>
</td>
<td>Step 5
Go back up to the main menu and set a Project number for your work with the button in the lower left.</td>
</tr>
<tr>
<td>
</td>
<td>Step 6
Select Line Scan.

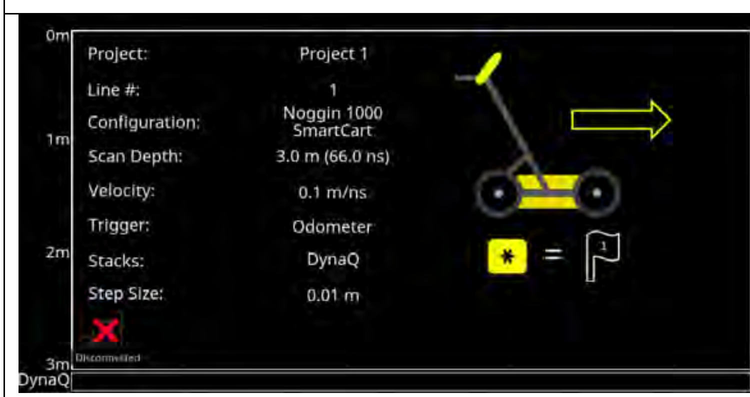
This is the end of the testing process. Now you are ready to collect real data.</td>
</tr>
</table>



Step 7
Set your Line Number, make sure GPS status is green.

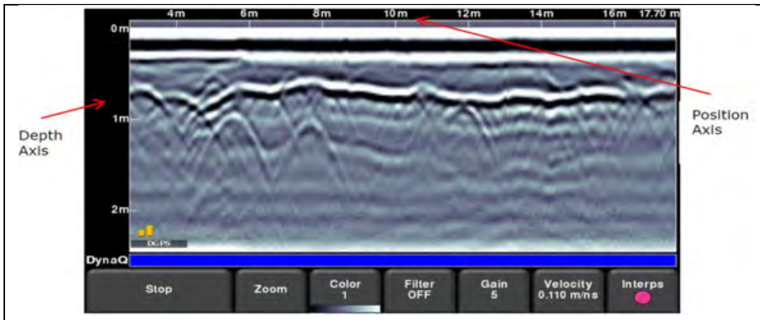
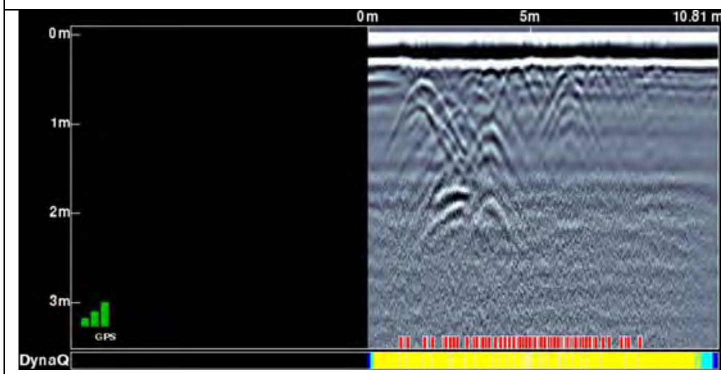


Step 8
Press **Start** to start your line scan.



Step 9
At the beginning of your line scan, you will see an initial screen with your System Configuration settings and a depiction of the SmartCart with a forward arrow.

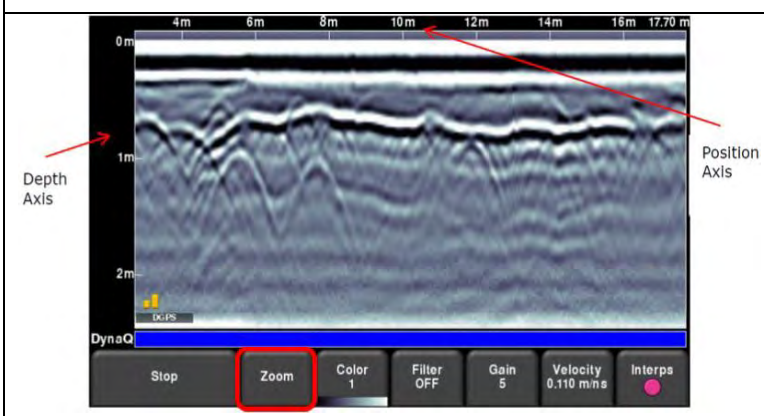
Once you start walking forward with the cart, the data will scroll in from the right of the screen

<table>
<tr>
<td>
</td>
<td></td>
</tr>
<tr>
<td>
</td>
<td>Step 10
Check the color of the DynaQ bar below the data.

The bar will be dark blue if you are walking at the right speed.

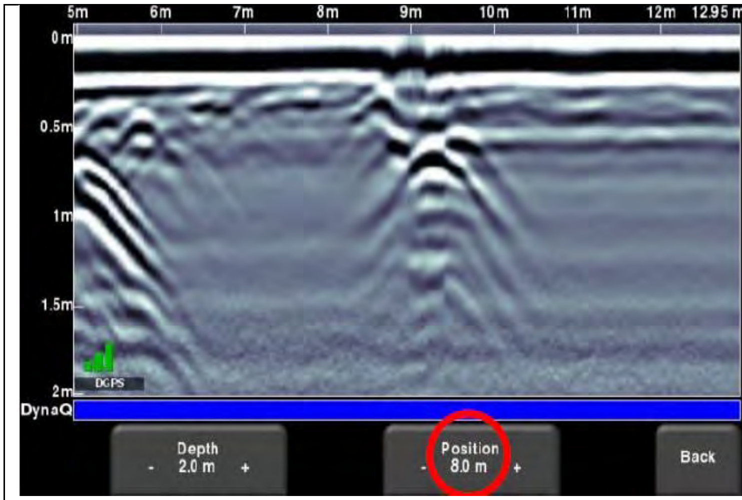
If the bar turns light blue, you are walking too fast.

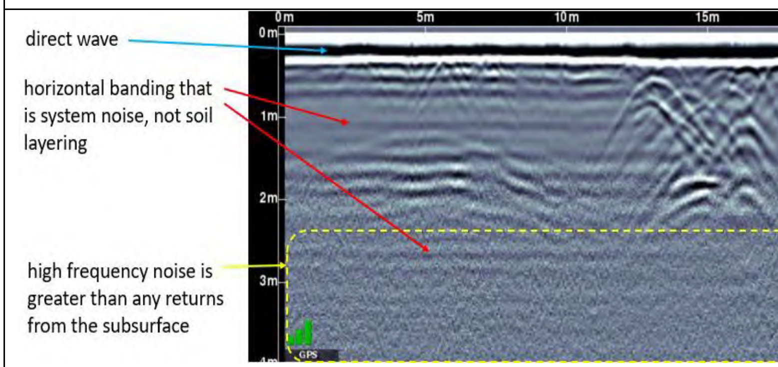
If the bar turns yellow or white, you are walking too fast for proper data collection. Slow your pace with the cart if this happens

Tip: Red bars will appear above the DynaQ menu to indicate where data could not be collected (skipped traces) due to fast pacing.</td>
</tr>
<tr>
<td>
</td>
<td>Step 11
Adjust the Zoom on your data as needed.

Set the Position to 8 m or more to display that length across the window and make it easier to see lateral variations in your profile. The whole line will be saved and can be viewed later.

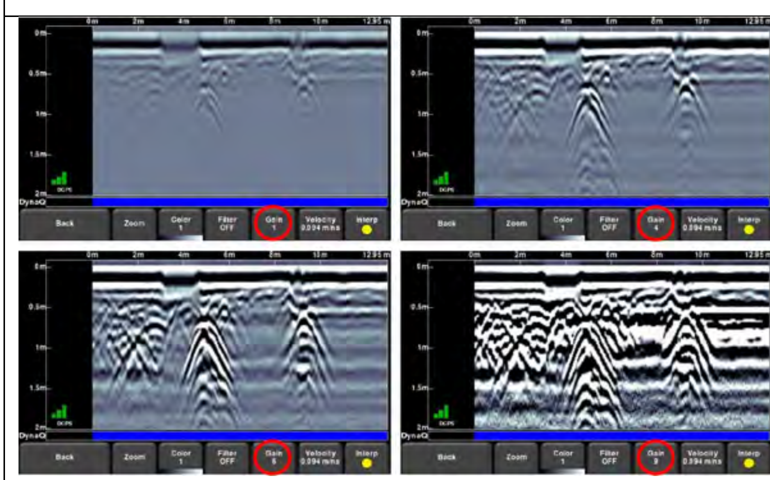
Tip: Do not hit the Stop button! That will end your line prematurely.</td>
</tr>
</table>



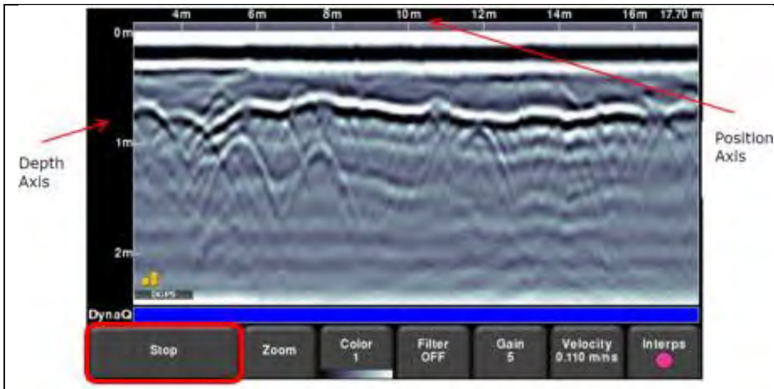
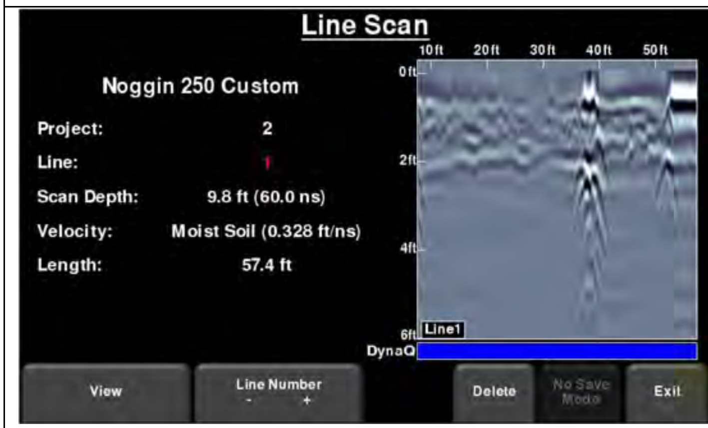


Step 12
If you are only seeing noise at lower depths, you may want to reduce the **Depth** to the range in which you are acquiring meaningful returns. Reminder: whatever your zoom Depth is set to, only Data to that depth will be exported.

You may not see the system noise as shown in the example above if your **Gain** is set to a low value. The following figure discusses the Gain.



Step 13
Change the **Gain** as needed to see your data more clearly. This is just an amplification factor for plotting and will not change the actual data.

	*Step 14* When you are finished with your line, press the **Stop** button.
	*Step 15* You can review your whole line after finishing. In the Line Scan menu, select the number of the line you have collected, and **View.**
 	*Step 16* Export your data. With the DVL turned on, insert a USB drive into the port on the DVL. If you do not see a window stating that "A USB device has been connected," it means that your USB drive has an issue. Try reformatting the drive or using another drive

Using string as a guide for a Line Survey

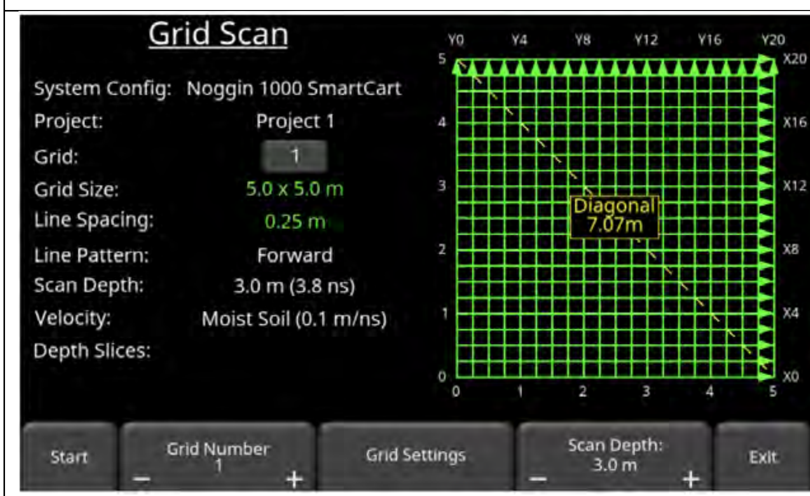
1. **Cut string sections** at your desired length, or you can use the measuring tape as a guide to line up your cart
2. **Stretch your guide string or measuring tape alongside the cart** in the X-direction a few cm from the cart, but close enough that the person pushing the cart can try to maintain a uniform distance between the cart and the guide string.
3. **Push the cart following the guide string**.

5. Doing a Grid Survey

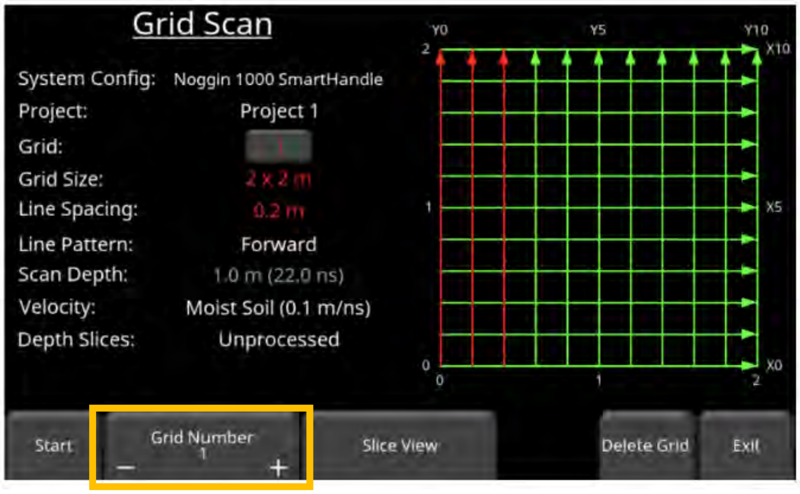
Using the Noggin GPR System

Taken from the Noggin GPR Operation Guide from Sensors and Software who manufactures the GPR carts used by the EPIC. Please see the Guide for more details.

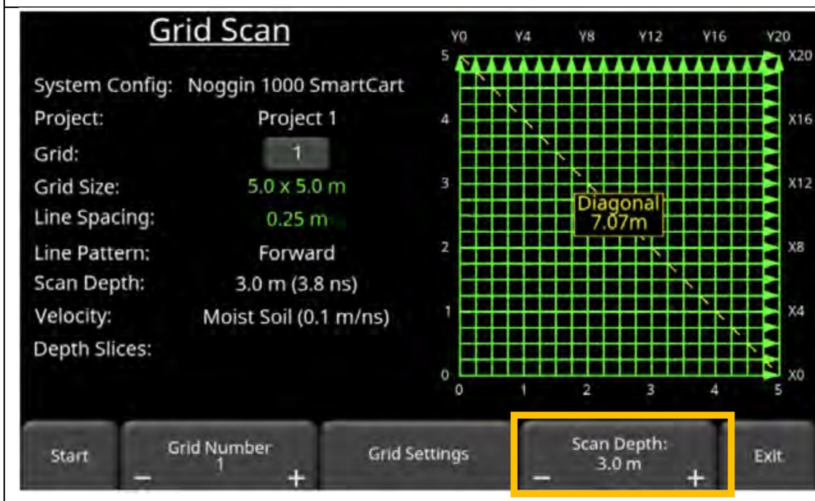
Step 1
From the main menu, ensure you are in the desired project then press the Grid Scan button to enter the Grid setup menu.



Step 2
The grid scan setup screen will allow you to set parameters of the grid, before data acquisition begins. Information about the grid is displayed on the left side of the screen, including whether the depth slices are processed. The right side of the screen shows an image of the grid setup and lines to be collected, including direction. It also shows the diagonal or hypotenuse measurement of a right-angle triangle; this is valuable when you are measuring out your grid.

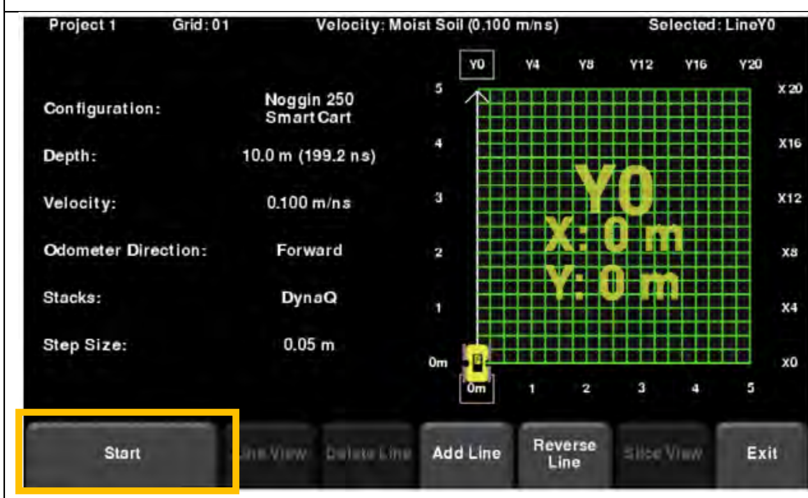


Step 3
Select a grid number and Grid Size by pressing the + and - buttons under Grid Number at the bottom of the screen. Grids that contain no data will have some text and grid lines shown in green, whereas grids containing data will have the text and grid lines shown in red.



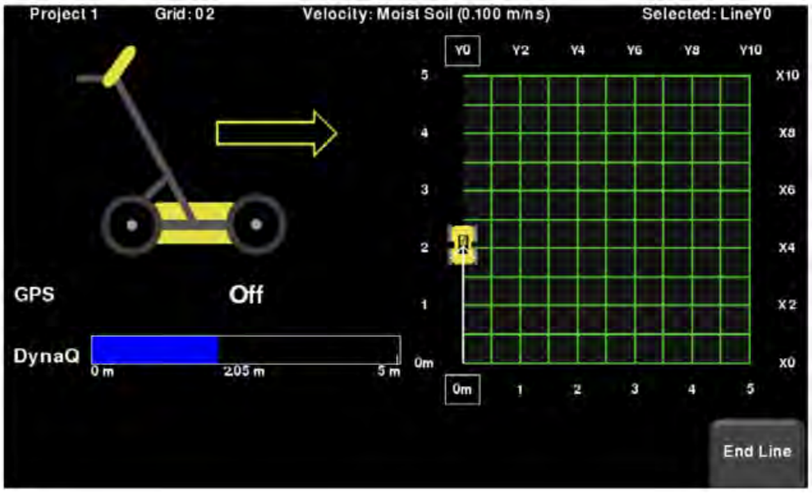
Step 4
Set the Scan Depth by pressing the + and – buttons to set how deep the scan should be.

Tip: the deeper you go, the more depth slices will be generated in SliceView mode. If a minimum of 3 lines are collected, the SliceView option will be enabled. You can press Slice View to create depth slices for the gridded area.

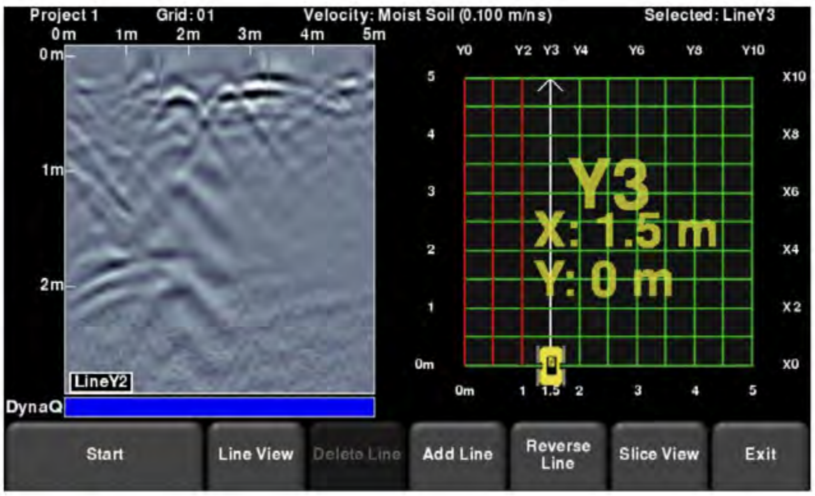


Step 5
Press Start when all the parameters are setup and data collection is ready to begin. Push the system in a straight line towards the end of the line. Your current position (or distance travelled) is displayed in real time immediately below the DynaQ status bar.

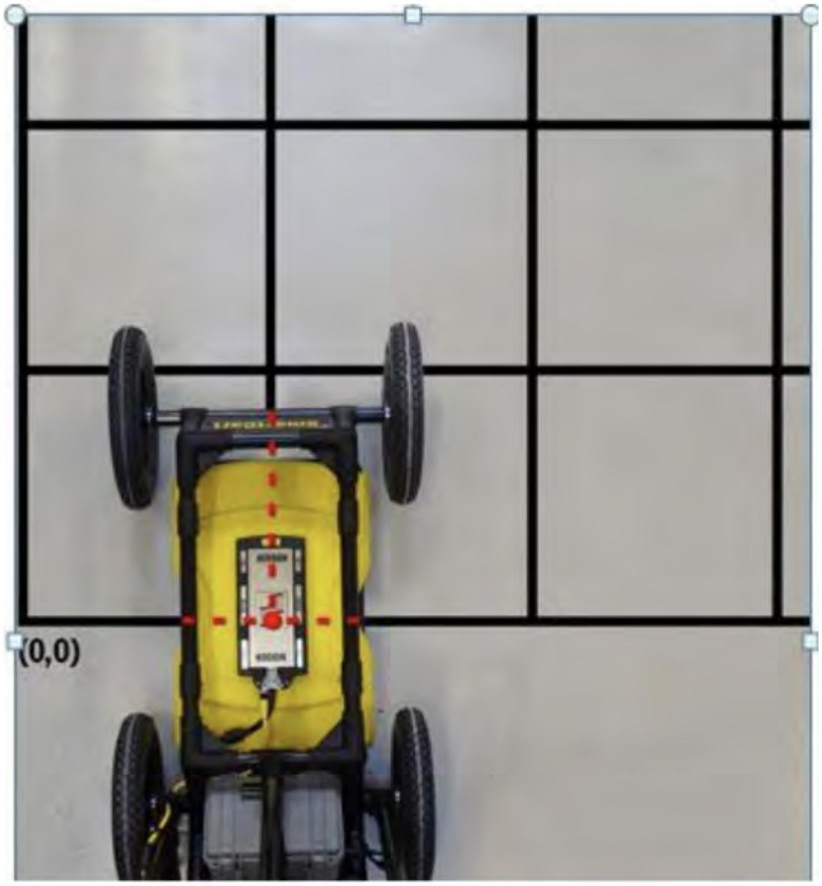
If Grid Line Stop is set to Auto, the system will automatically stop acquisition once that distance has been covered. If it is set to Manual, you will have to manually press End Line when you are done.



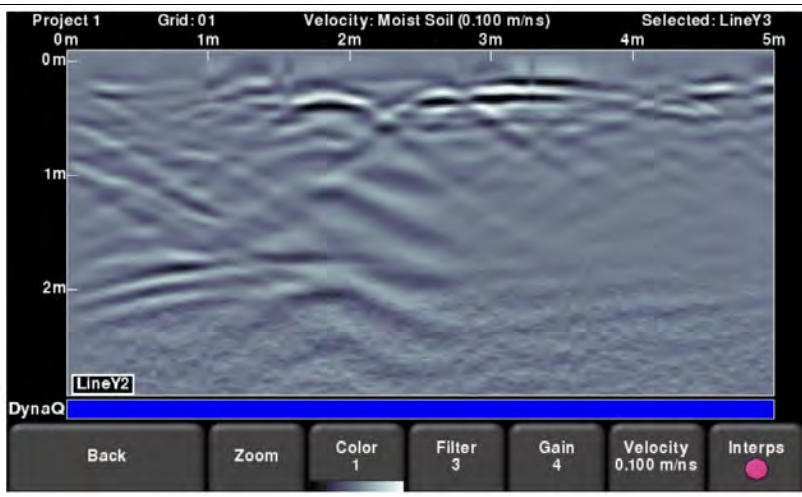
Step 6
As you are collecting a line, you must move in a forward direction. If you back up more than two step sizes during collection, it will stop and make you re-collect that line.



Step 7
Once data is collected, the Grid Line will turn red and the system will beep twice. The current line will now advance to the next one and is shown in white. The remaining lines to be collected are shown in green.

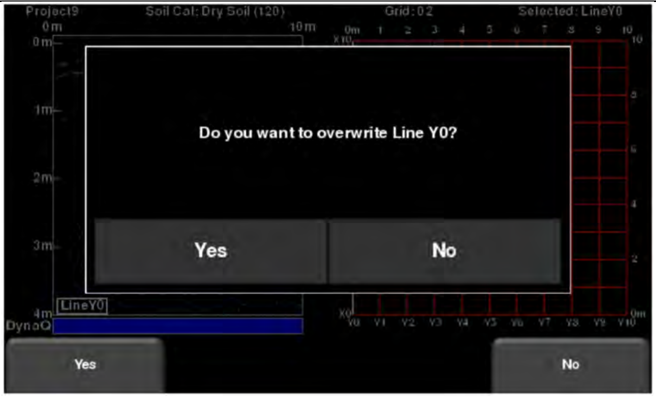
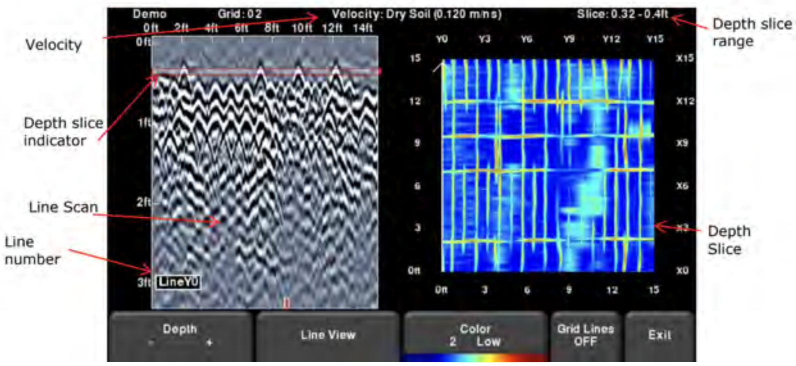


Step 8
Move to the start of the next line and repeat the process. The grid image will always display the line number (e.g. Y3) and the position of your line, relative to your origin. Once all the lines are done in one direction, it will automatically prompt you to collect lines in the other direction.



Step 9
You may want to recollect a line if you make a mistake, or maybe just view a line. Use the 4-way directional keypad to highlight different X and Y lines. The selected line will always be in white. Collected lines will be in red and lines remaining to be collected will be in green.

To recollect a line, press Start. You will be prompted with a message asking if you want to overwrite that line. Press Yes to proceed.

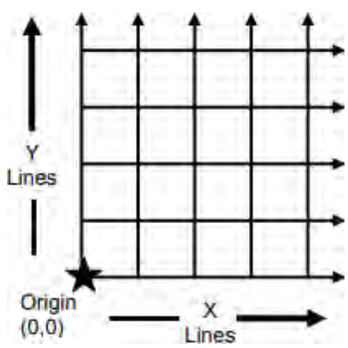
<table>
<tr>
<td>
</td>
<td></td>
</tr>
<tr>
<td>
</td>
<td>Step 10
Once you have finished collecting all the grid lines, you may press Slice View at the bottom of the screen to view your depth slice.

Tip: Before the data is processed and depth slices created, you must ensure the velocity is accurate; this will result in the most accurate and sharpest images.</td>
</tr>
</table>

Designing a Grid Survey

Recommendations before acquiring a grid:

- Make sure you establish your origin as follows-



- The recommendations for *maximum* spacing between lines are
  - 250 MHz antennas: 0.5 m (2 ft)
  - 500 MHz antennas: 0.25 m (1 ft)
  - 1000 MHz antennas: 0.10 m (0.5 ft)

With these spacings between lines it's better to collect smaller, more manageable grids. With 11 lines each direction, you can acquire a 5 m by 5 m grid with 250 MHz antennas.

- If you know the direction of pipes or other buried features, set up the grid so that X line directions will cross the pipes perpendicularly, and you don't need to collect lines in the Y direction. Adding additional length to lines in the X direction doesn't cost much time.

- Time spent laying out the grid carefully and lining up the cart carefully at the start of lines will really pay off.

- Students can cycle in and out of pushing the cart and watching data acquisition, but it really requires one person taking notes to keep checking that the positions on the ground match up with those shown on the screen.

Setup your Grid
See also the Grid Quick Guide at the end of the document.

1. ***Determine the size and orientation of your grid***. Measure and record the length and width of your allotted space. For best results, try to align the primary target with the grid layout so that it is parallel or perpendicular to grid lines. Make sure to leave enough space at the start and end of the lines for the cart to turn around.
2. ***Choose a corner to be the grid origin***. When choosing an origin, consider the GPR line directions within the grid and any possible collection issues, such as the angle of the sun at the survey time, slope, car or foot traffic if applicable.
3. Mark the Origin. Secure the zero (0) mark on the tape measure to the origin using a spike or marker (plastic flag or plastic tent stakes can work well). You will be making a right triangle to form the basis for your grid.
4. ***Measure and mark the base*** along the horizontal axis of your survey space. This will be distance A.
5. ***Measure and mark the height*** of the triangle, distance B.
6. ***Define your line spacing***. Choose a spacing interval for your grid lines and mark the ground at each interval along the two axes you have currently defined. It can be helpful to make two kinds of marks for major and minor intervals.
7. ***Flip the measuring tape over*** the long edge of the right triangle, leaving the origin and the distance B marker in place.
8. ***Mark the fourth corner*** of the grid.
9. ***Mark the major and minor intervals*** along the new axes created. Your grid will now be a full square or rectangle ready for survey.

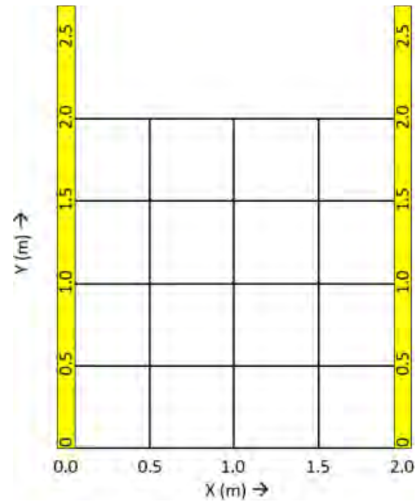
Using string as a guide for a Grid Survey

If you cannot make marks on or drill stakes into the ground in the grid setup, you can make a guide string.

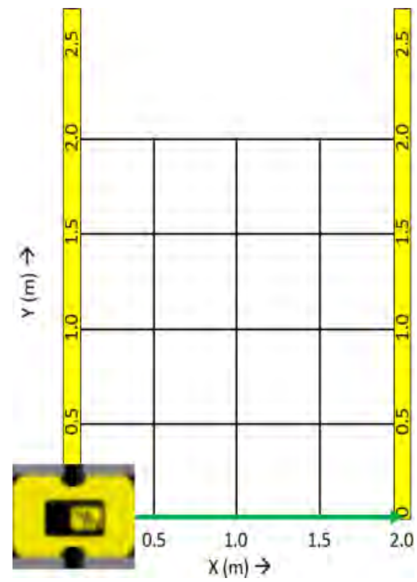
Using the neon-colored construction string:

1. **Cut string sections** about 3 meters longer than your longest grid dimension.
2. **Tie the string ends around weights**, these can be rocks or small barbells.
3. **Mark the four corners** of the grid.

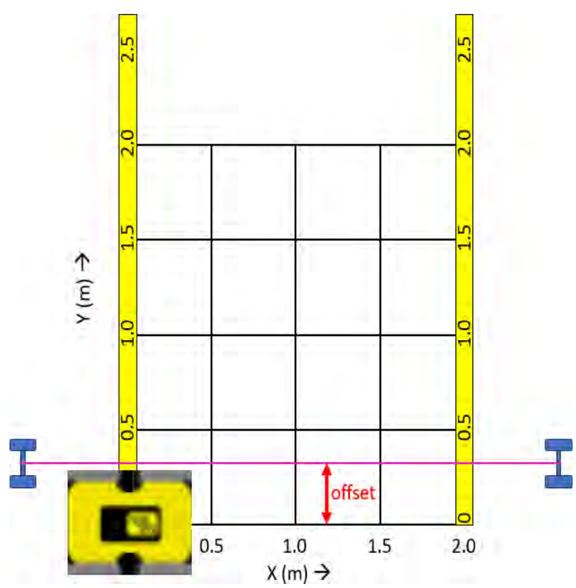
4. **Stake down two survey tapes** along the Y-direction boundaries of the grid with their zeros where Y = 0. Use plastic non-metallic stakes. These tapes need to be firmly staked down on both ends, so they won't move as the cart is pushed over them.



5. **Stake out the ends** in the Y-direction at least 50 cm past the end of your grid.
6. **Move the cart** so the antennas are centered over the origin of the grid, ready to go in the X-direction.



7. **Stretch your guide string alongside the cart** in the X-direction a few cm from the cart, but close enough that the person pushing the cart can try to maintain a uniform distance between the cart and the guide string. Then measure the offset distance in the Y direction between the Y = 0 line and the guide string.
8. **Push the cart following the guide string**, being careful to stop when the center of the antenna is aligned with the edge of the grid. (If you find that the distance along the GPR profile doesn't match your grid size, you may need to recalibrate the odometer. See the Noggin User's Guide.) Then move the string up to the position to guide the next line in the X direction.
9. **Move the cart up to start the next X-line and continue** to survey lines along the X-direction until the X-axis of your grid is complete.
10. **Move the two measuring tapes** so that they lie along the edges of the grid in the X-directions.
11. **Rotate the string** similarly rotated to the other direction.
12. **Survey line-by-line in the Y-direction** one at a time similar to the X-axis lines.



6. Data Acquisition Tips

- Make a sketch of the experiment in your field notebook, sketching locations and direction of each line. This may be especially important if you have to work under canopy and lose GPS positioning. It can also be useful to take screenshots during data acquisition showing maps, as you acquire. These will be included in the project export when you download the data.
- It's really helpful to have the person taking field notes keep track of the line number used in the GPR software, the position along the tape, and the guide string location. The notetaker can call out string locations to people at each end of the line.

Offset = 37 cm = 0.37 m
Plan: even lines forward, odd lines reversed
All distances in meters
Forward = west to east, Reverse = east to west

Line #	Antenna Position	String Position	Direction	Notes
X0	Y=0	Y = 0.37	For	
X1	Y=0.5	Y = 0.87	Rev	rock in way after 1.7 m
X2	Y=1.0	Y = 1.37	For	

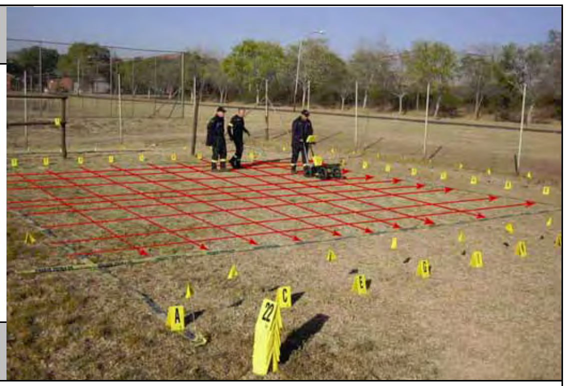
- After you are finished, if you have pounded-in stakes survey tapes and can't get them out, hit them on the side to create a bigger hole and then pull them out.

Grid Setup - Quick Start

Grids are often used when surveying with GPR, and laying out a grid with straight edges and all the corners at 90 degree angles can be difficult. This guide outlines a simple method for accurately constructing a grid of any size using readily accessible materials. Please refer to the GPR system or EasyGrid manual for additional details.

YOU WILL NEED

1. **A tape measure** long enough to measure the dimensions of your grid.
2. **Corner spikes**
3. **A field marking tool** (chalk, spikes, marking discs, etc., depending on your location).
4. **Optional: a second person to mark corners**

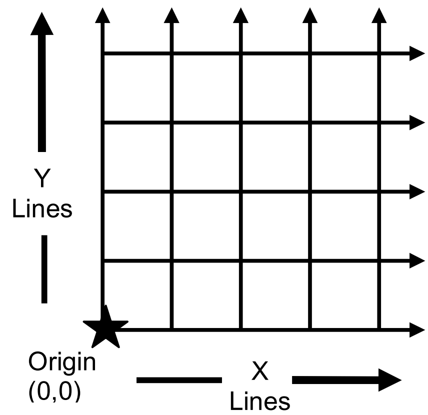


SET UP A GRID

1 **Determine the size and orientation of your grid.** For best results, try to align the primary target with the grid layout so that it is parallel or perpendicular to grid lines. Make sure to leave enough space at the start and end of lines for the cart.

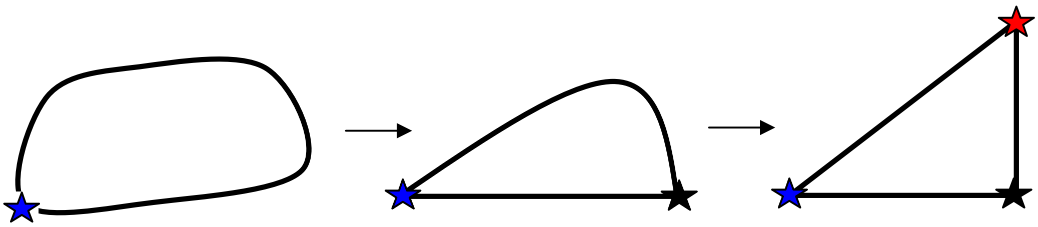
2 **Choose a corner to be the grid origin.** When choosing an origin, consider the GPR line directions within the grid and any possible collection issues (sun angle, slope, traffic, etc.).

3 **Mark the origin.** Secure the zero (0) mark on the tape measure to the origin (using a spike, etc.). Consult the **Grid Dimensions** table on the back of this sheet, unwind the tape measure to **Distance C**, and pin this point to the origin as well.



4 **Measure out Distance A** along the grid baseline. Secure the correct point (using a spike, etc.).

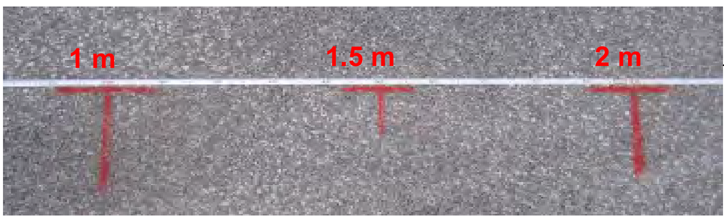
5 **Measure out Distance B** along the y-axis of your grid**.** Pull the tape tight.



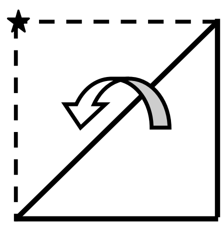
Step 3: mark the origin — Step 4: measure Distance A — Step 5: measure Distance B

You have now formed a right-angle triangle: the first half of your grid.

6 **Define line spacing.** Choose a spacing interval (ex 0.5 m or 2 ft) for your grid lines and mark the ground at each interval along the two axes you have currently defined. It can be helpful to make two kinds of marks: one for major divisions and one for minor divisions.



7 **Flip the tape** over the long edge of the triangle, leaving the origin and the Distance B marker in place, and mark the fourth corner of the grid.



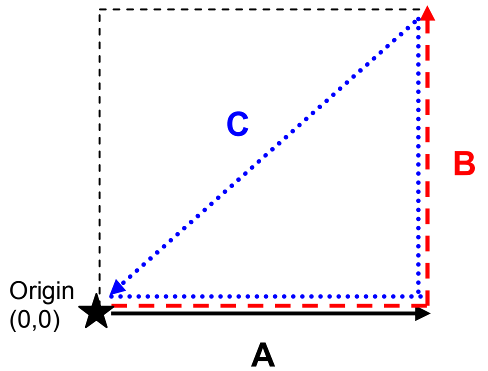
8 Mark the ground at the desired line spacing interval along the two new grid axes.

Your grid is now complete and ready to be scanned!

GRID DIMENSIONS

The following tables list some common grid dimensions and the measurements needed when following this grid setup guide. You can create your own custom grid sizes using a simple calculation:

- **Distance A** = length (L) of your grid
- **Distance B** = length (L) + width (W)
- **Distance C** = L + W + $\sqrt{L^2 + W^2}$



Grid Dimensions Table: Metric Units

Grid Size			Setup Dimensions		
Length (m)	Width (m)	Area (m^2)	Distance A (m)	Distance B (m)	Distance C (m)
5	5	25	**5**	**10**	**17.07**
5	6	30	**5**	**11**	**18.81**
5	7	35	**5**	**12**	**20.60**
5	8	40	**5**	**13**	**22.43**
5	9	45	**5**	**14**	**24.30**
5	10	50	**5**	**15**	**26.18**
10	10	100	**10**	**20**	**34.14**
10	12	120	**10**	**22**	**37.62**
10	14	140	**10**	**24**	**41.20**
10	16	160	**10**	**26**	**44.87**
10	18	180	**10**	**28**	**48.59**
10	20	200	**10**	**30**	**52.36**
15	15	225	**15**	**30**	**51.21**
15	20	300	**15**	**35**	**60.00**
20	20	400	**20**	**40**	**68.28**

Grid Dimensions Table: US Standard Units

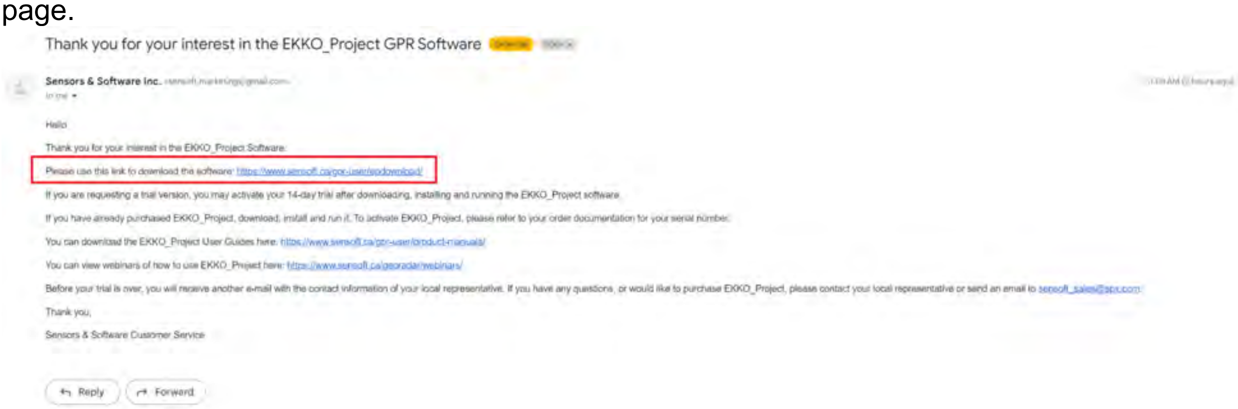
Grid Size			Setup Dimensions		
Length (ft)	Width (ft)	Area (sq ft)	Distance A (ft)	Distance B (ft)	Distance C (ft)
15	15	225	**15**	**30**	**51’ 2½”**
15	20	300	**15**	**35**	**60’**
20	20	400	**20**	**40**	**68’ 3½”**
20	25	500	**20**	**45**	**77’**
20	30	600	**20**	**50**	**86’ ½”**
20	40	800	**20**	**60**	**104’ 8½”**
30	30	900	**30**	**60**	**102’ 5”**
30	35	1050	**30**	**65**	**111’ 1”**
30	40	1200	**30**	**70**	**120’**
40	40	1600	**40**	**80**	**136’ 7”**
30	60	1800	**30**	**90**	**157’ 1”**
40	50	2000	**40**	**90**	**154’ ½”**
40	60	2400	**40**	**100**	**172’ 1½”**
50	50	2500	**50**	**100**	**170’ 8½”**
60	60	3600	**60**	**120**	**204’ 10”**

GPR EKKO Project Software Download Instructions (V6 R2)

For more detailed installation instructions, please see the [SenSoft EKKO_Project Installation, Registration & Troubleshooting User Guide]()

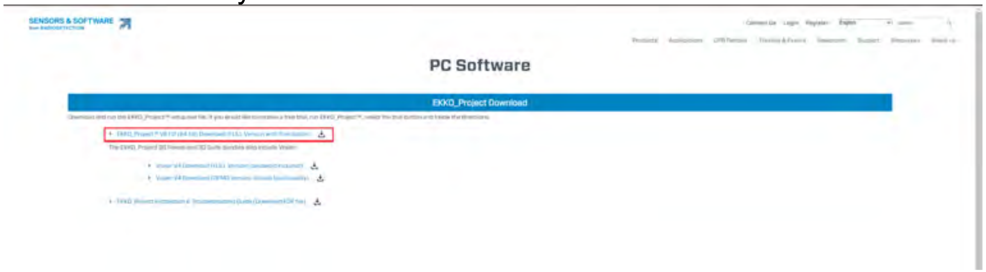
1. Enter your information on the [EKKO Project Download form]() and click Submit.
    a. This page is associated with [GPR Software Downloads]() from [Sensors & Software from RADIODETECTION](), and will send you an email to the address provided on completion.

2. Navigate to your email inbox to find the email from Sensors and Software Inc. titled *Thank you for your interest in the EKKO_Project GPR Software.*
    a. Be sure to check your Spam folder if you can't find the email in your main inbox.
3. In the email, use the first link to navigate to the [PC Software EKKO Project download]() page.



4. Download the EKKO_Project V6 R2 (64 bit) FULL Version with Trial option.

   a. The download may take a few minutes.

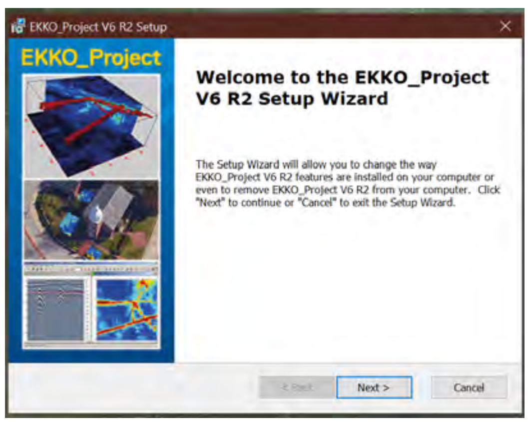


5. EKKO_Project_x64.exe will download to your device. Whether in your Recent Downloads in your browser or in a particular Downloads folder on your device, find and double-click EKKO_Project_x64.exe to run it.

6. Follow the instructions in the EKKO_Project Setup Wizard to install the software.

   a. Depending on your access, you may need to contact your IT Department to perform the installation.

   b. Be sure to allow the program to make changes on your device.



7. Double-click the EKKO_Project desktop icon or navigate to the program in your file manager to start the software.

8. Upon starting, the Sensors & Software Product License Activation window will launch. Do the following things in this window:

    a. Check the boxes next to the following modules:

        i. Ekko_Project V6 R2

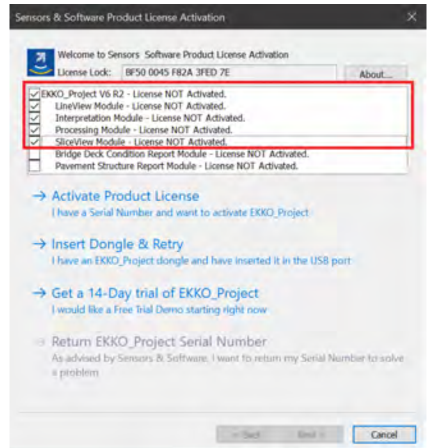
        ii. LineView Module

        iii. Interpretation Module

        iv. Processing Module

        v. Slice View Module

    b. Once the boxes are checked, select **Activate Product License/Get a 14-Day trial of EKKO_Project**



If you are using EKKO for teaching a course and will need EKKO Project to be functional for your students for more than 14 days, contact the vendor Sensors & Software and request extensions. Initiate this process **at least several days in advance**. S&S will need to know the emails associated with the software downloads.

David Dryden - +1 610-755-8061
Chris Kenney - +1 530-965-7351
https://www.sensoft.ca/contact-us-gpr/ - 800-267-6013

Mention that you are using a GPR Noggin borrowed from EarthScope Consortium.

GPR Unit 3: EKKO Project Software GPR Data Processing Quick Guide

Sarah Kruse (University of South Florida)

Introduction

Have you gathered your own GPR data? Are you ready to process it and see what lies in the subsurface? This guide will outline the general steps you will need to upload, clean, and process your data with the EKKO Project Software.

Although this guide will allow you to initially process your data, there are more details that may be required to fully analyze and interpret your data. The vendor, Sensors & Software, has a more complete EKKO Project User's Guide (as well as other Resources).

This guide was developed for EKKO Project V6 R2 and assumes that you already have GPR data that you or someone else collected. See also GPR EKKO Project Software Download Instructions.

Get Prepared

1. Ensure that you have a Windows OS device available with EKKO Project V6 R2 software installed on it.
2. Transfer your data from the Noggin GPR Digital Video Logger (DVL) to your computer using a USB device.
3. Move the files to a location where you will be able to find them in EKKO Project. For example, you may want to create a GPR Data folder in your Documents.
4. Launch EKKO Project by double-clicking the desktop icon or searching for the program in your device's program files.
5. Upon opening, the Getting Started menu will appear. Select the **Browse for Project File** button and locate your GPR data (.gpz file extension). You may also open a line file ending in the .DT1 file extension.

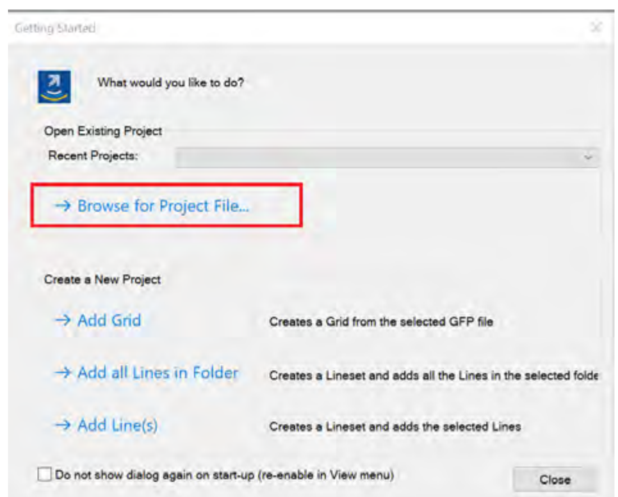


Figure 1: EKKO Project Getting Started

6. On opening, you should see the Project Explorer, with a preview of the GPR profile and possibly a model of the grid or path that the GPR unit took to get the data (if available).
7. Pause and get a broad look at the data in this view. Do you see any patterns in the hyperbolas? What path did the surveyor take to get the data?

8. Zoom or resize window to change vertical exaggeration to better see features of interest. In this example there is no signal coming from below 3 m depth, so just the top 3 m are selected by selecting the zoom button and dragging the mouse.

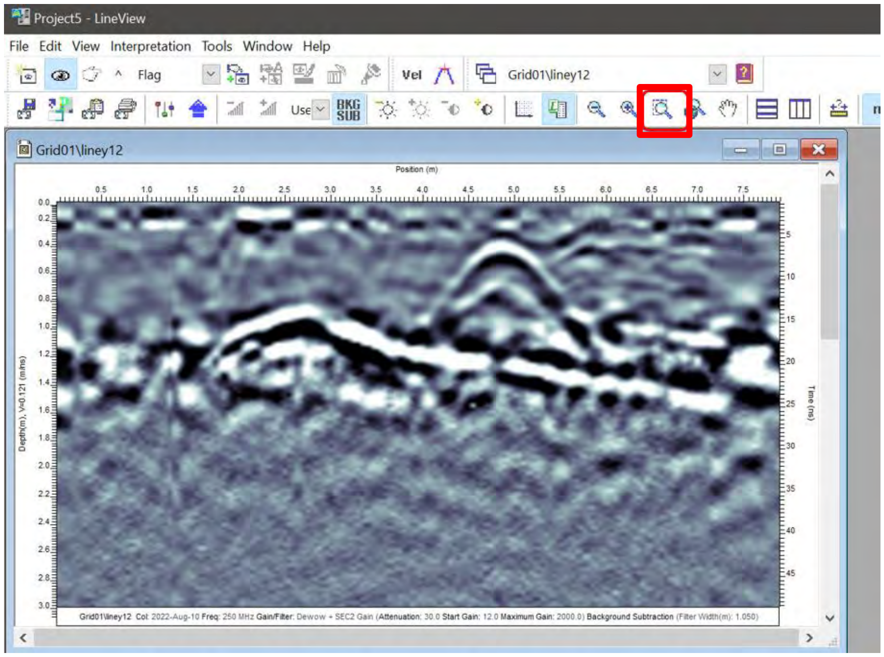


Figure 2: GPR profile with larger, more prominent features using the Zoom function.

Processing the Data

Data Cleaning

Though we can look at GPR profiles as they are recorded, we will need to clean our data to ensure we get the most out of it. Recall that we are looking for hyperbolas, the upside-down U's, that may indicate a point-like object in the subsurface. EKKO Project has tools that help us emphasize the hyperbolas we want to see and clear away things we don't want to see, like the direct wave.
We need to:

- Reduce the noise in our data
- Make sure we have the correct speed of the medium
- Get our data ready for export

9. If you have many lines of data, select one line to view using the Layer View window on the left.
10. Once your selected line has loaded, click Line View in the upper left-hand side of the Menu Bar.
11. The Project Explorer window will close and load the Line View window. Don't worry, you did not close the program, Line View just takes a few seconds to load.

12. You will see a new menu in Line View and just the GPR profile, unlike in Project Explorer that has the map view as well.

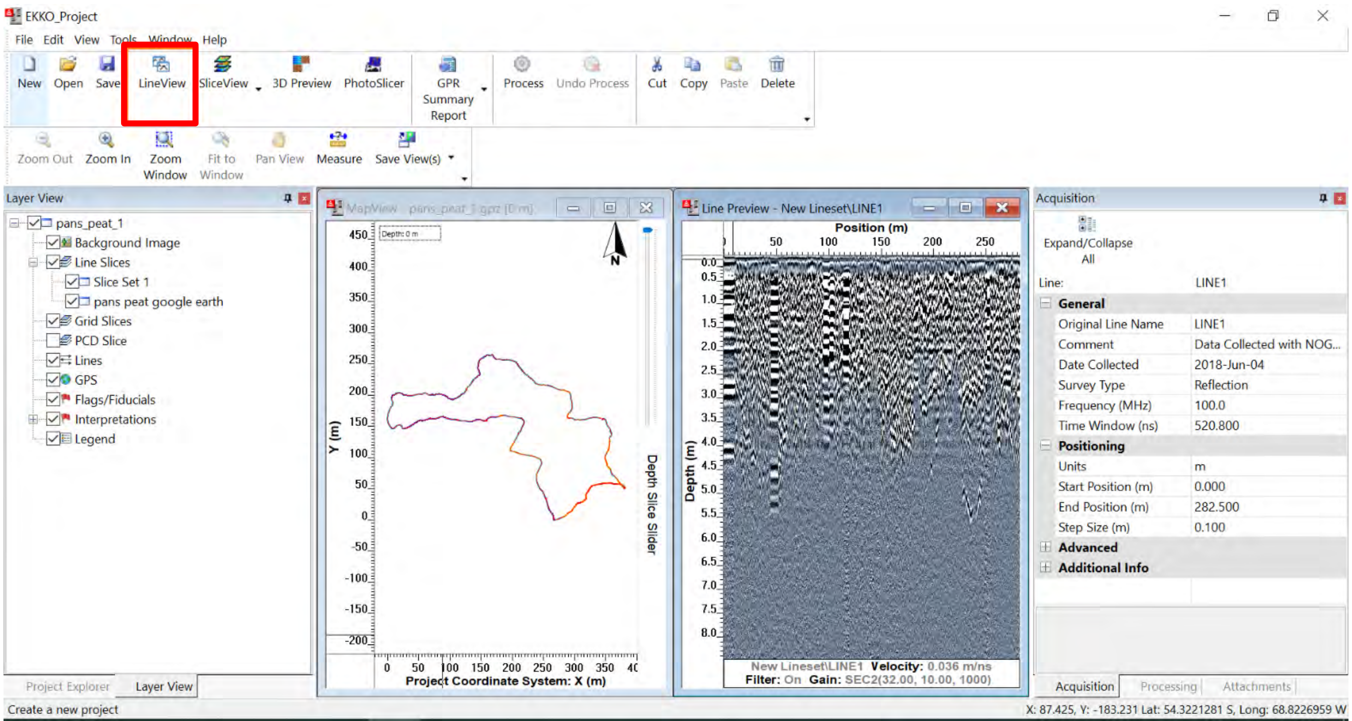


Figure 3: EKKO Project Explorer window with Line View highlighted.

Background Filter
Recall that in addition to buried features, a distinct straight-line signal will appear close to the surface. This is the direct wave that bounces between the transmitter and receiver of the GPR antenna, and it does not indicate any buried feature. EKKO Project provides a way to dim this band and make our data clearer.

13. In Line View, click on the Background Filter button to toggle the filter that gets rid of any horizontal banding in the data.
    a. Background Filter removes the average of all the traces. Any other signals that cause horizontal banding in your profile are removed as well. So double check the original data when deciding to leave Background Subtraction, it may make it more difficult to see any real horizontal features.

Gain
Recall that as GPR waves travel through the subsurface, they attenuate, or become weaker, the further they go. Attenuation can make buried features difficult to see with depth. Gain means amplification of the weaker energy arriving at the receiver at later times, or further down the depth axis. Adding gain to your GPR data is like adding additional contrast or brightness so signals in the data are easier to see. EKKO Project offers a few ways to adjust the gain in your data.

14. In Line View next to the Background Subtraction button, click on the Modify Gain dropdown menu.

15. Feel free to click on the different levels of gains in the dropdown menu and see what they do to your data. You can also adjust gain incrementally using the Increase and Decrease Signal Gain buttons to the left of the dropdown menu.
16. EKKO Project also uses specific algorithms to calculate the best gain for your data. Click Auto in the Modify Gain dropdown menu to allow EKKO Project to choose your gain for you.
    a. Even in geoscience, creating readable figures is both an art and a science: there is no perfect, one-size-fits-all solution. Though using Auto Gain is well-calibrated and convenient, it may not be the best way to see all the features in your data. Be sure to double check if there are any hyperbolas that are not captured when using Auto Gain
17. For more customizability and to see the gained data vs the original, select View from the Menu Bar and select Settings from that dropdown menu.
18. In the View Settings window that appears, navigate to the Gain/Filter tab. If you move your mouse around the GPR Data, the window will show each wiggle trace that makes up the GPR profile (black line) and how much that wiggle trace has been adjusted by the gain (red line). You can also view the gain curve by checking the Gain box

Changing the Color Palette

19. Also in the View Settings window, navigate to the Color Palette tab to change the color of your line image. Feel free to play around with the color settings to find which one works for you.

Determine the Radar Wave velocity

GPR waves will travel and attenuate differently based on the material it is traveling through. Though EKKO Project may offer a default ground velocity, it is important to determine the velocity that is specific to your survey site.

20. In LineView, visually scan and find a hyperbola that is distinct to you.
    a. If your dataset has multiple lines (multiple GPR profiles), feel free to select a new line with more distinct hyperbolas. Right click on the line in the Project Explorer Window, and select the LineView in the pop-up menu.
21. Adjust the window to a size and zoom where any hyperbolas are not too stretched out to see.
    a. Our eyes are most sensitive when the hyperbola wings are at about 45 degrees.
22. Choose how you will select the top of a hyperbola by clicking on the blue up arrow icon for the Time zero offset preference menu and choosing an option. Press OK when your preference is selected.
    a. If you would like this preference to apply to all the lines in your dataset, check the Apply to all open lines box.

23. Click on the Hyperbola Calibration button, the icon with the blue hyperbola with a red crosshair at the top. A thin red hyperbola will appear in the middle of your profile.

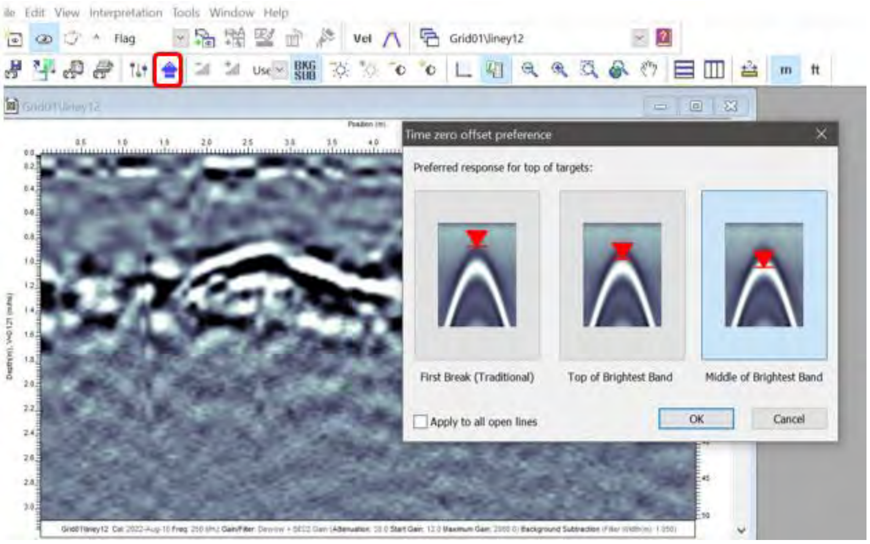
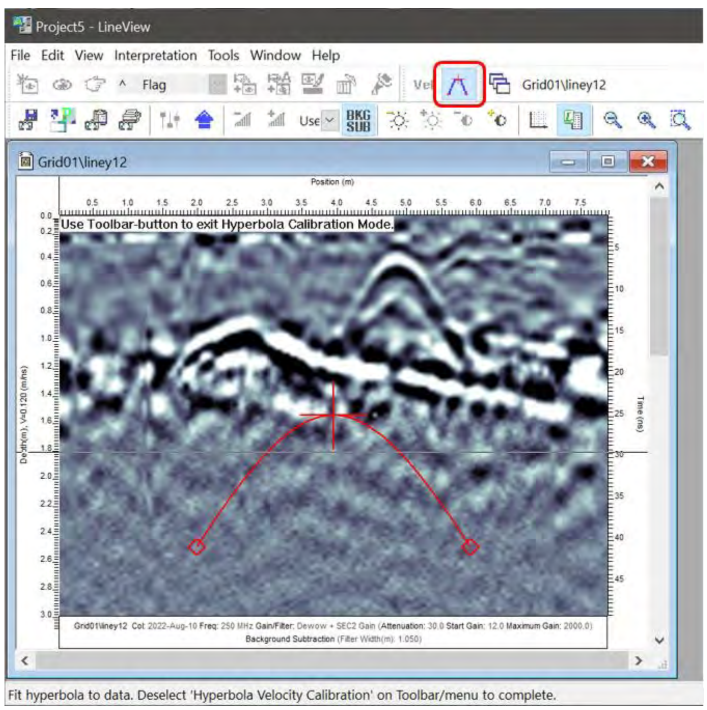
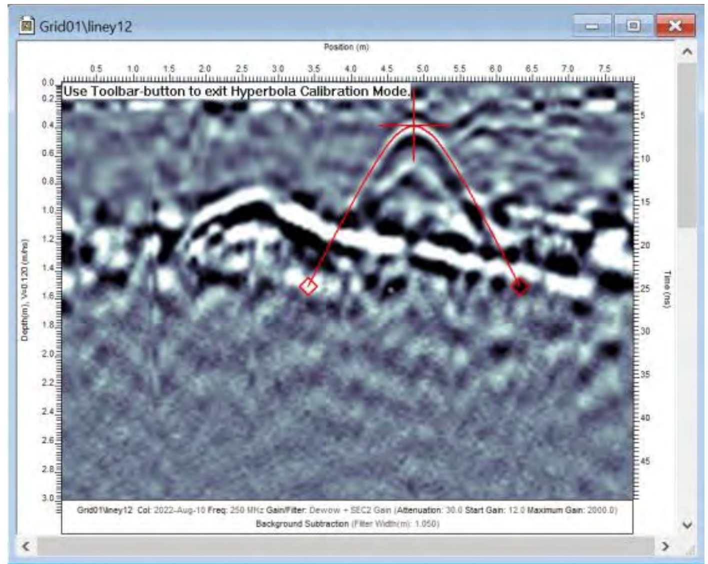


Figure 4: Time zero offset preference menu to choose where you consider the "top" of a hyperbola.

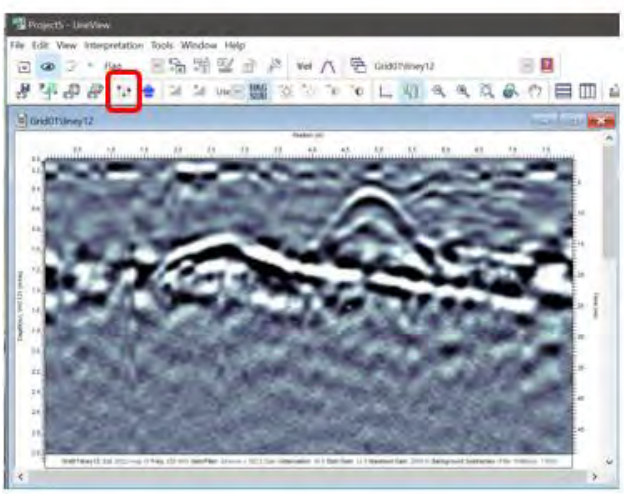
24. Click and drag the red crosshair in the sample hyperbola to the hyperbola in your profile, making sure the red crosshair is at the "top" of the hyperbola that you selected earlier.

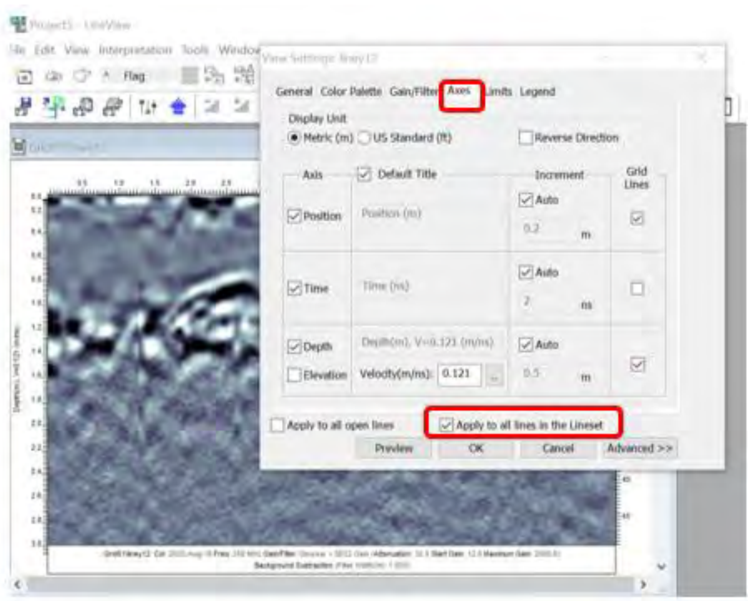


25. Adjust the diamonds on the ends to adjust the length and width of your parabola so that it matches the dimensions of the hyperbola in your profile.

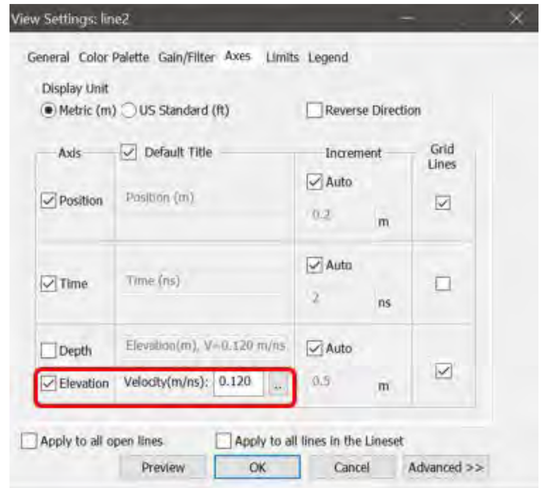


26. Your calibrated velocity will be displayed in text at the bottom of the screen. Record this velocity or take a screenshot to use later.
    a. If your dataset has multiple lines and you would like to apply the calibrated velocity to all of the lines in your dataset, save the selected velocity using the Modify Settings button and navigating to Axes and checking the box next to “Apply to all lines in the lineset.”
    b. Many materials have an average GPR velocity that researchers have agreed upon. Is the velocity you calibrated close to the standard? Double check the velocity of your material using the [GuidelineGEO article on GPR Velocity]() and recalibrate your hyperbola if you need to. Alternatively, you can search “GPR Wave velocity of [YOUR MATERIAL HERE]” in your search engine of choice.
27. Click the Hyperbola Velocity Calibration icon to leave Hyperbola Velocity Calibration mode. A menu will appear asking if you want to save your newly calibrated velocity.





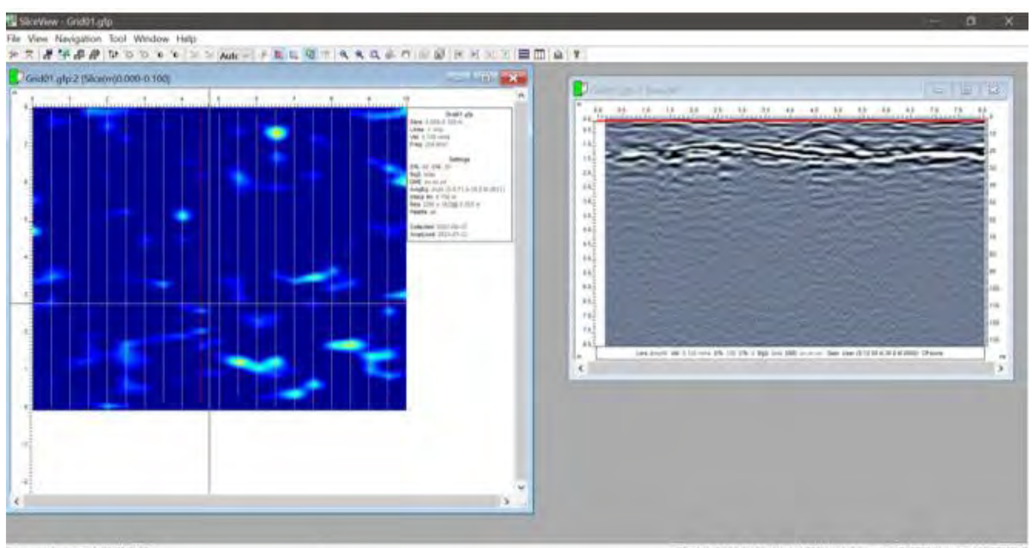
28. If you have significant elevation changes over the course of a line, you may want to apply a topography correction. In the same Modify Settings window under the Axes tab, check the Elevation box.



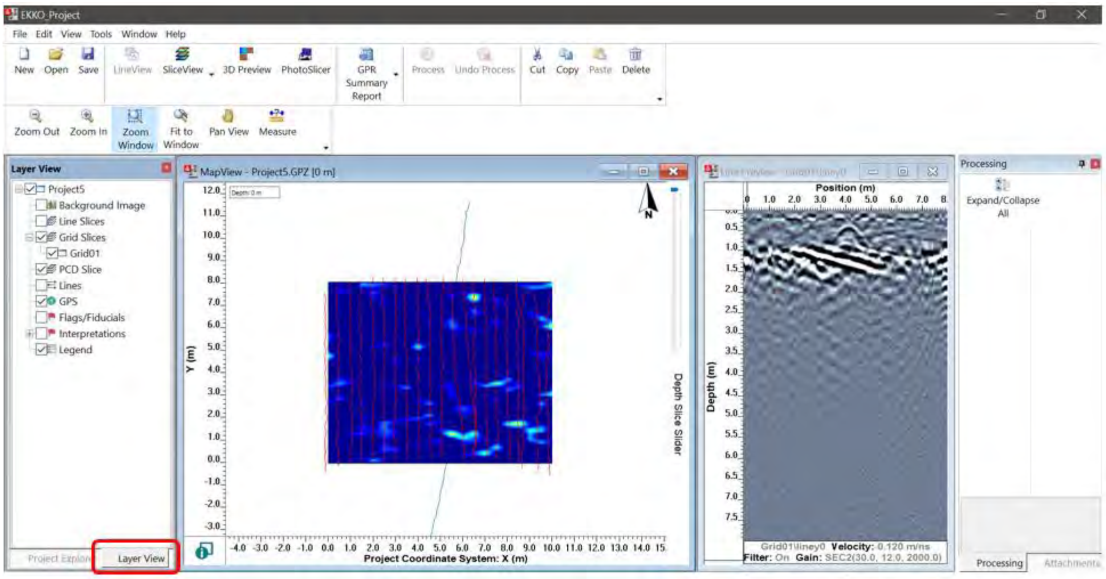
Exporting your Data

From 3D animations to maps, EKKO Project offers many ways to visualize your data.

29. Once you have calibrated a more accurate velocity for your data, save your profile as an image using any of the tools at the top left of the screen. You can:
    a. Save your image as a .png, .jpg, etc. to your computer using the floppy disc icon.
    b. Save the current window to your project profile in EKKO Project
    c. Copy the profile image to your clipboard
    d. Print the current image
30. Exit **LineView** using the large Exit button in the top left corner. Don't worry, you didn't close the program! This will return you to the Project Explorer
31. If your data includes a grid, select the grid, and click on the **SliceView** button. After some processing time, the **SliceView** window will appear and a new .gfp file will have been created.
32. *To look at different slices and lines*, move your mouse over the grid, yellow crosshairs will follow. If you click, it will pull up the nearest GPR line, which appears as a red line on the depth slide. The red line on the GPR profile shows the depth of the slice shown. Similarly, if you click on the profile it will pull up the corresponding depth slice.



33. You can use the Menu Bar to move through the depth slices and adjust the contrast.
34. Make a gif of the depth slices. Close up **SliceView**, go back to EKKO Project, select the **MapView** window. From the main menu at top, select View/Export Animation, select Depth, speed of choice.
    a. You can select what you want to appear in the gif by opening Layer View, which is a window that toggles with the Project Explorer window.



35. To save your current slice as a .kmz file, go to the SliceView dropdown menu and select SliceView-Lines. Here, double check that your calibrated velocity will be used to process the data, make sure the level of gain is being used, and change the color palette of the slices if needed.
36. Check the Export Data box and toggle the Google Earth (KMZ) radio button.
37. When you are ready, select **Process.**

You can now open Google Earth Pro on your computer and open the .kmz file of your data from within Google Earth. The geolocated path and depth slices will appear in the location they were taken in Google Earth!

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