LAB 6 SUPPLEMENT

**Using Earthquake Arrival Times to Locate Earthquakes**

In last week's lab, you used arrival times of P- and S-waves to locate earthquakes from a local seismograph network in Central Asia. In this lab supplement, we're going to learn a little more about modern seismic data and about how earthquakes are located. We'll be using some recent seismic data recorded by a couple of modern seismograph networks to locate earthquakes: (1) a seismic network operated by IU in schools around the Midwest, as part of the *IU PEPP Earthquake Science Program*, and (2) the *Global Seismograph Network (GSN)*, a research facility operated by the IRIS Consortium. For this exercise, we're going to use data from stations of the GSN to determine the location and origin time of a few recent earthquakes. The idea of this exercise is to learn how modern seismological analysis programs use the arrival times of seismic waves to determine the location of the earthquake.

**Digital Seismic Data**

Many modern seismograph stations, instead of recording with an ink pen and recording drum, send their signals directly to a computer. The computer creates "digital seismograms" by sampling the electrical signal in discrete intervals (in our case, about 20 times per second), and then recording the signal level in digital form in the recording computer's hard disk. The seismograms can then be played back in a variety of forms on a computer screen or laser printer. The records begin a minute or so before the P-wave arrival and continue through the surface wave train, up to an hour later.

**Computer Earthquake Location**

Typically, a computer location program starts with a trial epicentral location (i.e., a guess!), often based on the order of arrival of P-waves. It uses this trial location, together with an origin time and a standard Earth model, to *predict* the arrival times of seismic waves. The *observed* arrival times are then compared with the *predicted* ones, and the difference between the two is calculated as the "residual". The sum of all of the "residuals" is calculated as the "RMS misfit". The program tries to find a location that minimizes the misfit between the observed and calculated arrival times. Ideally, with the perfect location, the RMS value should drop to zero. In practice, it never does—because of errors in arrival time measurements, inadequacies in the Earth model, and errors in the location algorithm. To learn how this works, we’ll use a program that illustrates the computer location procedure:

**Using the Program EqLocate to Study Earthquakes**

We're going to use a student seismic program EqLocate to study these GSN records. Here's a quick primer to get started using EqLocate. A more detailed tutorial is available at http://www.iub.edu/~volcano/notes/EqLocate.htm.

1. Start the EqLocate software. From any of the Student Technology Cluster computers, go to the Start Menu ➔ Programs ➔ Departmentally Sponsored ➔ Geology ➔ EqLocate. An intro screen and a 'hints' screen should appear in front of an image of the globe. Click ‘Continue’ on the intro screen, and close the ‘hints’ screen to get started.

2. You can change the map view and zoom in using the arrow and plus and minus controls in the upper left of the screen. You can zoom in on the map and adjust the view to the approximate area of the earthquake that you wish to view. We’re going to start with an earthquake in the central U.S., so rotate the globe to put
Indiana close to the center, and zoom in until the map view covers the region from the eastern seaboard to Oklahoma and the Great Lakes to the Gulf Coast.

3. Click on "Open Event" from the "File" menu. When the open menu appears, select the file "EqLocate data", then select the folder "darmstadt". Use your mouse to highlight all of the files, then click "OK".

4. A set of about ten seismograms, from different seismograph stations around the Midwest should appear on your main panel. The station name (4- or 5-letter code) is shown in the upper left of each seismogram. Triangles indicating the locations of each of the recording stations should appear on the map.

5. We’re going to be picking P-wave arrival times for each of these stations, and then using the arrival times to locate the earthquake hypocenter. In order to get precise arrival times, though, we’ll have to expand the time scale, by using the up/down arrows beside the numeric box at the lower left of the seismogram window. It’s probably best to increase the time scale to its maximum value (11). Use the scroll bar beneath the set of seismograms to move through each of the seismogram windows.

6. Then, we’ll look for the P-wave arrival, where the first signal appears to increase above the ‘background noise’. The amplitude can be increased or decreased by using the up/down arrows beside the numeric box to the left of each of the seismograms. This will help you see the P-wave arrival more clearly. Select the time when the trace first appears to depart from the background signal. Once you’ve identified the P-wave arrival, left-click on it using your mouse. Note that the P-arrival time appears in red text in the left-hand side of the window. Record the P-wave arrival time on Table 1 on the following page.

7. Once you’re happy with a pick, move on to the next seismogram. Use the time scroll bar to find when the P-wave signal first appears. Use the amplitude box beside the seismogram to turn up the gain if necessary. Again, record the P-wave arrival time in your Table 1. Repeat this process until you have picked P-arrival times for each of the stations.

8. Once all of the seismograms have been picked, scale back the time and amplitude scales to their original settings (1), and all of the seismograms should appear back in view.

9. Next, we’ll start working on the earthquake location, using a trial-and-error method similar to that used by a computer earthquake location program. We are going to start with a trial location. Given the location of an earthquake hypocenter and a standard Earth model, we can compute the predicted times that a P-wave will arrive at any station of known location. By comparing these predicted times with the observed times, we can decide how best to move our trial location to a better location that will better match the observed and predicted arrival times. This process is repeated until an ideal location is determined. Before we start, though, we’d better set the hypocenter depth to a reasonable value; otherwise our predicted arrival times will all be off. Go to the “Control” menu, and select “Set Depth”. Enter 5 (km) for the trial depth, and click “OK”

10. Start with a trial location someplace close to the recording network. For this experiment, you might try a location some place in central Michigan. Click on the map and a trial epicenter will appear as a blue star.

11. You will note a few other changes on the window. First, an additional pair of colored bars will appear on the seismograms.
   a. The blue and green bars indicate the times predicted for the P-wave and S-wave arrivals, respec-
   tively. You may note that in some cases the blue bar appears before the red bar, indicating that the
   predicted time is early with respect to the observed; in other cases, the blue bar may appear after
   the red bar, indicating that the predicted time is late. Theoretical arrival times that are earlier than
   the observed arrival time indicate that the trial epicenter needs to be moved farther from that
   station. Similarly, theoretical arrival times that are later than the observed arrival time indicate
   that the trial epicenter needs to be moved closer to that station.
   b. You also may note a change in the map. A series of black lines and black triangles appear. These
   show the predicted distances to each of the seismic stations. The positions of the small black
   triangles and the lengths of the lines are calculated by the program and represent the expected
distance to the corresponding station if the trial epicenter is correct. A mismatch in the positions
of the triangles means that the trial epicenter needs to be moved. If the estimated distance is less
than the epicenter-to-station distance (the line connecting the epicenter to the small black triangle
does not reach the station), the epicenter needs to be moved toward that station. Similarly, if the
estimated distance is greater than the epicenter-to-station distance (the line connecting the
epicenter to the small black triangle goes through the station), the epicenter needs to be moved
farther from that station.

c. A third item should appear on your display: a yellow box indicating the latitude, longitude, and
depth of the trial hypocenter, along with an indicator of the quality of fit ("RMS error"). The
smaller the RMS value, the better. Our goal is to reduce the RMS to as small a value as possible.
d. Finally, one more item will appear on your map—if your location has a good enough match with
the observed seismograms. A small colored dot will appear at the trial location, corresponding to
the RMS value of that location. The color bar on the left-hand side of the map will serve as a
legend for the RMS values.

12. The search can be continued by selecting another trial epicenter using the positions of the small black
triangles as guides to which direction to move the epicenter. A relatively small RMS error solution can
usually be found with a few more trials using this approach.

13. Once you’re close to a final location, you may want to zoom in on the epicentral area and repeat trial
locations until you get as good a fit as possible. By clicking rapidly around a possible location, you will
begin to see a ‘bull’s eye’ pattern appear. This bull’s eye will help give you a sense of the error around
the final epicentral location.

14. You may note that all of your stations fit the observed times well except one or two. This could mean that
you’ve made a bad pick of P-wave arrival times at those stations. If so, go back to the seismogram
window, and see if you can improve the pick on the arrival time. Then repeat the earthquake location
procedure with the revised arrival times.

15. When you have a final best location, record the origin time, latitude, longitude, and depth in Table 2.
Record the origin time also in Table 1, and use it to calculate the travel time of the P waves from the origin
to each of the recording stations.

Finally, compare the location you’ve obtained with that from the National Earthquake
Information Center (US Geological Survey). The easiest place to get this data is from a web-
based data request system ("Wilber II") operated by the IRIS Consortium. Set your browser to:

http://www.iris.edu/cgi-bin/wilberII_page1.pl

and select the time period of your earthquake, noted by year and 'quarter'. In this case, because
the earthquake occurred during June of 2002, select Q2 2002, and either click on an earthquake
symbol (if you think you know where it is) or "List All Events" from the link above the map.

If you're having trouble using this form, or want to see a more complete listing of
earthquakes from any date, you can also use their catalog search form at:

http://www.iris.edu/quakes/eventsrch.htm

and select a search period in terms of dates, locations, or magnitude ranges. Use the origin time
to find the earthquake of interest.

Once you’ve gotten a hang of it with one ‘regional’ earthquake location, we’ll try the same
thing with two other events representing global (or ‘teleseismic’) locations. One of these is a
shallow-focus, or crustal, earthquake; the other a deep-focus event.
From the ‘File’ menu, click on ‘Close Event’ and the seismogram windows should disappear. Zoom the map back out to a global view, and then re-center the globe on Alaska, with a view over the North Pole. Click ‘Open event’ from the File menu, select ‘Alaska 1’ from the EqLocate Data folder. Select all of the seismograms from this folder and repeat the procedure you applied above, entering the data in Tables 3 & 4.

Finally, we're going to repeat the procedure with seismograms from a deep-focus event, a famous (because it’s a monster!) earthquake that occurred in Bolivia in 1994. Again, from the ‘File’ menu, click on ‘Close Event’ and the seismogram windows should disappear. Zoom the map back out to a global view, and then re-center the globe on South America. Click ‘Open event’ from the File menu, select ‘S. America 1’ from the EqLocate Data folder. Select all of the seismograms from this folder and repeat the procedure you applied above, entering the data in Tables 5 & 6. This time, however, there's a catch: the earthquake occurred at a depth distinctly different from the 10 km depth that we assumed for the other two events. In this case, you're going to have to try a few different depths and find the best location—in other words, the one with the lowest RMS value. If you do it correctly, you'll match all of the observations well, and will find a depth that corresponds closely with the global seismic network observations. First try the location at the assumed 10 km depth. Then go to the Control menu and select three additional depths—400, 500, and 600 km—and see which one provides the best match with the observed data. In other words, you're trying to find the lowest RMS value of all. Enter your result in Tables 5 & 6.

Table 1: List of Arrival Times of Recording Stations (event 1)

<table>
<thead>
<tr>
<th>Seismic Station</th>
<th>Arrival Time (P)</th>
<th>Origin time (hr:min:sec)</th>
<th>P-wave travel time (sec)</th>
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Table 2: Earthquake Epicenter estimates

<table>
<thead>
<tr>
<th></th>
<th>Origin Time</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Depth</th>
<th>RMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>EqLocate epicenter</td>
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<tr>
<td>USGS epicenter</td>
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Geographic Location: __________________________
### Table 3: List of Arrival Times of Recording Stations (event 2)

<table>
<thead>
<tr>
<th>Seismic Station</th>
<th>Arrival Time (P)</th>
<th>Origin time (hr:min:sec)</th>
<th>P-wave travel time (sec)</th>
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### Table 4: Earthquake Epicenter estimates (event 2)

<table>
<thead>
<tr>
<th>Origin Time</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Depth</th>
<th>RMS</th>
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<td>EqLocate epicenter</td>
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<tr>
<td>USGS epicenter</td>
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### Table 5: List of Arrival Times of Recording Stations (event 2)

<table>
<thead>
<tr>
<th>Seismic Station</th>
<th>Arrival Time (P)</th>
<th>Origin time (hr:min:sec)</th>
<th>P-wave travel time (sec)</th>
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### Table 6: Earthquake Epicenter estimates (event 2)

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<thead>
<tr>
<th>Origin Time</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Depth</th>
<th>RMS</th>
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<tbody>
<tr>
<td>EqLocate epicenter</td>
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<td>USGS epicenter</td>
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Geographic Location: [Blank]

**Warning:** When you exit the computer program, you’ll get a slew of error messages. Ignore the messages and keep hitting ‘Cancel’ or ‘OK’ to get out!
Questions

1. How does this location procedure differ from the one you used in last week’s lab exercise?

2. What information do you think the computer program needs in order to compute the predicted arrival times of P-waves at each of the recording stations?

3. The RMS value is supposed to go down close to zero. Why does the value remain above zero? In other words, why is the match between observed and predicted arrival times always imperfect?

4. Based on your experience with this exercise, what characteristics of the recording seismic network are most important in controlling the quality of earthquake location determinations?

5. Why might this be important to the military for detecting underground nuclear explosions?

6. What do you think of this program?