

Earthquake Location Exercise

Introduction

In this exercise we will calculate the epicentral location of two earthquakes recorded by the Japan Meteorology Agency. The first earthquake (the Sanriku earthquake of 15th November 2005) is a relatively simple example of a local recording of an event. The second (the Toikadio earthquake of 5th September 2004) is a more complicated recording of an event.

The aims of this exercise are:

- To understand how rms residual can be used to indicate confidence in a location;
- To highlight the importance of good, reliable phase picks;
- To see how station distribution effects location precision;
- To see how the velocity model affects the location;
- To investigate a complex recording of an earthquake and produce a reasonable explanation of the record.

Data

For this exercise we will be using the data in the folders “Sanriku_vel” and “Toikaido_vel”. These are .sac files of waveform data, the filename gives the station and component (vertical, north, or east) the data were recorded on. For example, ERIMO.Z.sac is the vertical component of the Erimo seismometer.

NOTE: The seismometers that recorded this data are short period instruments. Therefore, they record the high frequency body waves very well, but do not record the lower frequency surface waves.

Instructions

Basic guides to using the computer programs needed to do this exercise are given at the end of this document.

1. Open EqLocate and load the vertical component velocity data for the Sanriku earthquake (i.e. the files ending in “.Z.sac”). Rotate the view of the globe and zoom in on the stations in Japan.
2. Pick the P arrival on the recordings in the window on the right.
3. By selecting many possible locations for the earthquake, find the best fit location and map out the RMS distribution around this location (see next section for one possible solution).
4. The green lines on the data window are the estimated S arrivals for the picked location. The S arrival is not used to calculate the RMS, however by visually comparing the data and the green line, does the lowest RMS (from the P location) have the same location as the best fit to the S arrivals?
5. From the file menu close the event (if this crashes the program, don’t worry just reopen it). Then, load the vertical component velocity data for the Toikaido

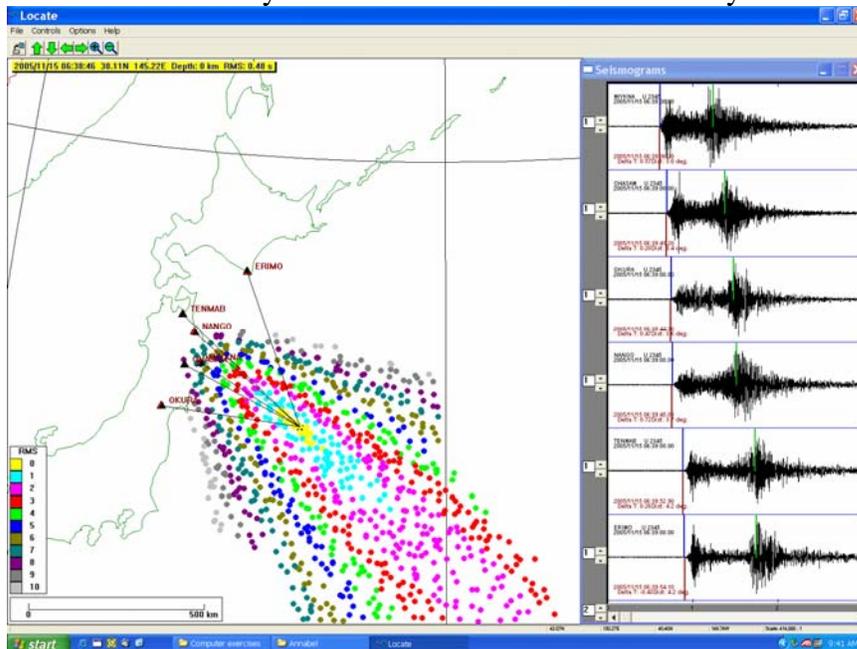
earthquake (i.e. the files ending in “.Z.sac”). Rotate the view of the globe and zoom in on the stations. Note that this data look different to the Sanriku event – Sanriku had 2 clear burst of energy associated with the P and S arrivals, this data contains 3 bursts of energy. To understand the 3 bursts of energy on the data, and confidently identify the P and S phases, investigate the data further using SeisGam2K. Start SeisGram2K and open all channels (all files in the Toikaido_vel folder). SeisGram2K shows all 3 components for each seismometer and will allow further investigation of the data through zooming, filtering, particle motion plot, etc. Use these feature to determine which type of arrival (P or S) each of the energy bursts are – the particle motion plot may be very useful for this. Once you know the arrival types, think of an explanation for appearance of the seismogram.

6. Once you understand the data, return to EqLocate and locate both the epicenter and the main burst of energy from the event.

Answers and Comments

3) Find the best fit location and map out the RMS distribution around this location.

RMS distribution: see below. Note that the colored zones are not circular, instead they are approximately oval, with the long axis stretching away from the station array. This is the affect of poor station distribution with all stations on one side of the earthquake. As a result the distance off-shore for the earthquake is not well known. Therefore, there is increased uncertainty in the estimated arrival time for any tsunami generated.



Location above:

38.11 N, 145.22 E d=0km, $T_0= 06:38:46$

Other locations:

JMA: 8.027N, 144.943E, d=45km, $T_0=06:38:51.3$

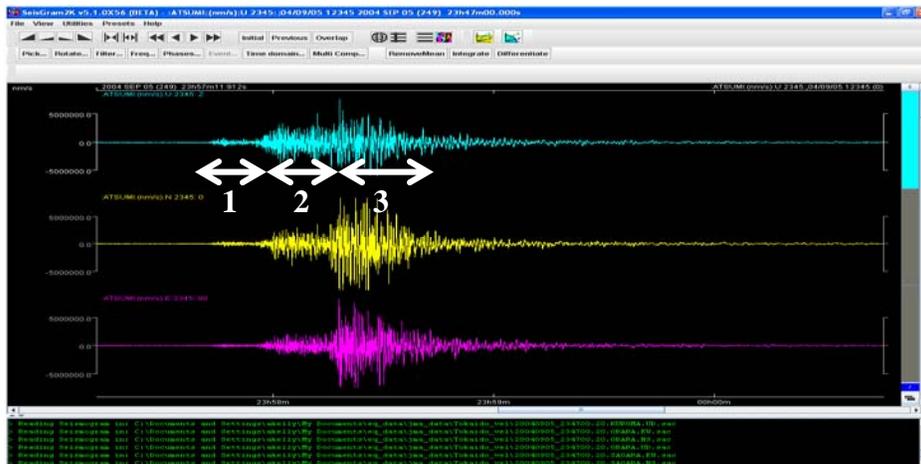
NEIC: 38.101N, 144.925E, d=11km, $T_0=06:38:51$

4) Does the lowest RMS (from the P location) have the same location as the best fit to the S arrivals?

No, the best location for the S arrivals is closer to the Japanese coast than the lowest RMS location. This may indicate a problem with the velocity model used in this program. As this is a simple program we cannot change the velocity model (we can't even see what model it uses. However, as the program is mainly designed for teleseismic location it probably has a very simple crustal + upper mantle velocity model that is a global average, and isn't very appropriate for the Japanese subduction zone setting). However, this also shows how the difference in S and P arrival time is much more sensitive to epicentral distance than just the P arrival time, and constrains distance from the coast when the station layout is not perfect. For this reason the JMA location uses both P and S arrivals to calculate epicentral location.

5) Determine which type of arrival (P or S) each of the energy bursts are in the Tokaido event, and explain the appearance of the seismogram.

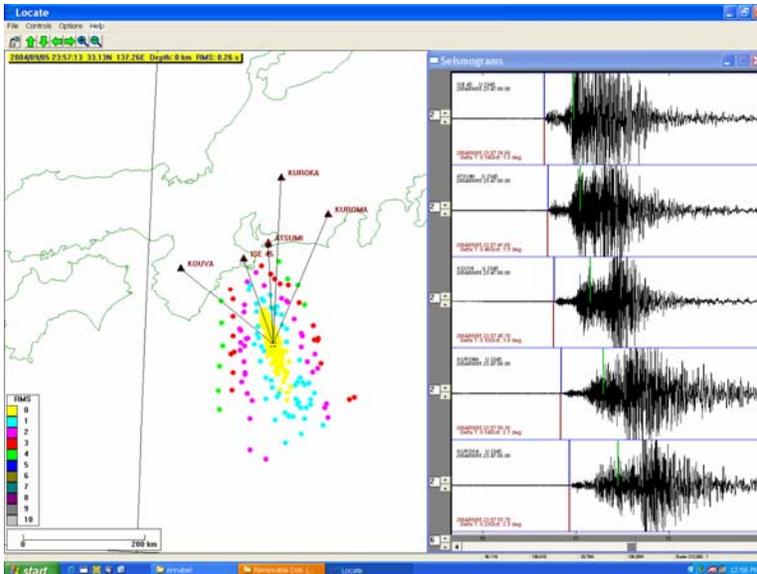
The 3 bursts of energy are highlighted in the figure below. The 1st and 2nd are both P arrivals and the 3rd is an S arrival.



It is likely that the S arrival in the 3rd burst of energy is associated with the P arrival in the 2nd burst, and that the S energy associated with the first P wave arrival occurs sometime during the 2nd burst but is too low amplitude to be clearly seen on the seismogram. Looking at the P amplitudes, we can explain these seismograms if the earthquake had quite a long rupture duration with a change in energy release after ~20 seconds. In this scenario the initial rupture released relatively little P and S energy (producing the 1st burst of energy), then after some time the rupture suddenly released more P and S energy (producing the 2nd and 3rd bursts of energy).

6) Locate both the epicenter and the main burst of energy from the event.

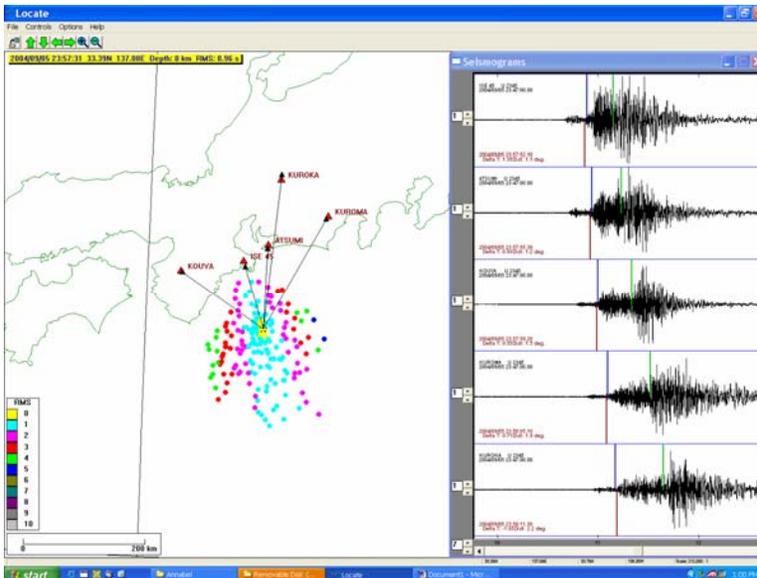
To locate the epicenter we can only use the first P arrival, the S arrival is lost in the 2nd burst of P energy. A possible EqLocate location is shown below:



This location is:

Loc= 33.13N, 137.26E, d=0km, T₀=23:57:13
 Other hypocentral locations for this event are:
 NEIC: Loc= 33.184N, 137.071E, d=10km, T₀=23:57:18
 JMA: Loc= 33.137N, 137.14E, d=44km, T₀=23:57:16.8

To locate the main burst of energy we can pick the onset of the high P amplitudes and check that the green line in EqLocate matches the onset of the 3rd burst. A possible location is:



The above location is:

Loc= 33.39N, 137.08E d=0km T₀=23:57:31
 This is offset by 18 seconds and ~30 km to the epicentral location above (however, the picks have quite high uncertainty so this offset is very approximate).
 The Harvard CMT location (which is a similar type of location) is:
 Loc= 33.13N, 137.22E, d=12km, T₀=23:57:43.2

The Computer Programs

The computer programs used in this exercise are relatively simple codes and not operational standard. However, in being simple and requiring user control they highlight several features of earthquake location, such as station distribution control on how rms maps out. The main program for location will be EqLocate. SeismGram2K will be used in addition for looking more closely at the data.

EqLocate

EqLocate is a simple program that can be used to locate events using .sac files of events or example earthquakes included in the source code. Details will be given below, but to use click on the P-wave arrival on each station and then guess at the epicenter. You will be shown lines toward each station from the selected epicenter which will guide you toward your next pick. The rms error is displayed in text at the top of the screen plus colored dots will record your past guesses.

Controlling the view

When EqLocate is opened you will see a globe. In the top left corner the  buttons rotate the globe and zoom in or out. Either from the file menu or by using the  button you can open the recording of an earthquake. This will bring up a window of seismograms on the right and will place red triangles on the globe. These triangles are the station locations (see Figure 1). Note: the triangles can always be seen, even if the station location is on the other side of the world, so care must be taken to be certain the correct hemisphere is being looked at.

Picking P-wave arrivals

The window containing data can be resized to assist in picking the P-wave arrivals. To pick a P arrival simply point the mouse at the onset of the phase and left click. The recording can be resized using the  buttons to the left and below the data.

When a P-wave arrival is selected a dark red line appears on the data indicating the time of the pick.

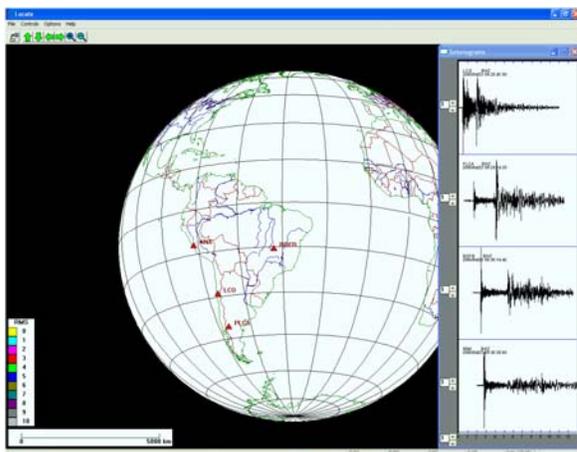


Figure 1 EqLocate after first opening a data set.

Locating the earthquake

After picking the P arrivals, select a potential location on the globe by left clicking where you think the earthquake may have occurred.

After selecting a location there are several changes to the screen:

- On the globe a star indicates your pick and black lines (ending in triangles) extend towards the station locations. These lines

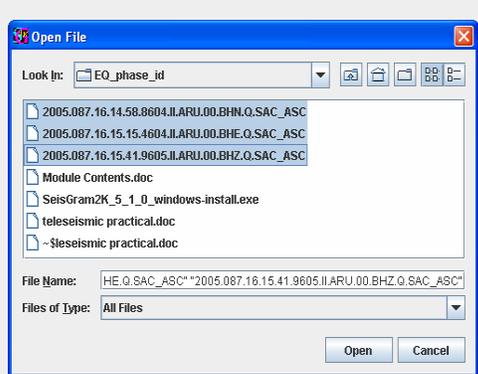


Figure 2 "open file" menu in SeisGram2K

- indicate the best-fit arrivals times for the P-wave and S-wave arrivals for this location.
- If the RMS error is less than 10 seconds, a colored dot appears at your location. The color indicates the value of RMS error, with the key to the colors given in the bottom left corner of the screen.

indicate where the station would need to be for your location to be correct, they can be used to help guide the next guess at location.

- In the top left corner of the screen a yellow box gives the details on the earthquake origin time, location and RMS error (root-mean-square difference between picked P arrival times and best-fit arrival times for an earthquake in this location).
- In the data window, blue and green lines

To improve the location click in a new location, using the black lines reaching toward the stations, the blue and green lines on the data, and (if shown) the colored dots recording RMS error as guides.

The depth of the earthquake can be adjusted through the “Controls” menu.

SeisGram2K

SeisGram2K can be used for viewing and basic processing of seismic waveform data. Below is a brief outline of some of the features of SeisGram, more detail can be found on Antony Lomax’s website <http://alomax.free.fr/seisgram/SeisGram2K.html>.

Loading data

The data can then be loaded by selecting “file”, then “open file”, then using the window that pops up to select data. Go to the folder with the required data and highlight the files as shown in Figure 2. Click on “open”. On the second screen titled “open channels” do not change the defaults, simply click on the “open” button.

The data will appear as color coded wiggles: for multi-component data different colors will indicate different components of the seismometer, for example vertical components are colored blue, north components yellow and east components pink (Figure 3).

On the left side of the screen the units of the y-axis are given and across the top of the data the information on the time and date of the beginning of the record and the seismometer that recorded the data.

At the very bottom of the screen the green text keeps a log of activity you’ve made.

Viewing options for multiple station records

If you open the seismograms from several stations there are several options on ways to view this data:

- 1) clicking on the globe symbol  the data are all aligned to a common time frame;
- 2) The symbol to the right, either  or , switches between locking the separate stations to the same timeframe and having individual timescales (which affects the way the data zoom);
- 3) The next symbol to the right, either  or , switches between viewing multiple stations or only one station. In the single-station option, a scrollbar on the right of the screen allows you to change which station is viewed.

Note: when multiple station are viewed any command (such as zooming or filtering) issued using buttons or menus, is only carried out on the record highlighted by a colored bar on the right-hand edge of the screen.

Zooming and changing scale

There are several way to zoom in and out of portions of the data:

- 1) The  buttons expand and contract the timescale;
- 2) left clicking once to the left and once to the right of the area of interest zooms in (but only if no submenus are open);
- 3) click and hold to drag a box around the area to zoom in on.
- 4) To return to earlier view of the data the two buttons   can be used.

Particle motion plots

Particle motion plots representing the ground motion recorded in the seismograms can be generated by going to the “view” menu then “Particle Motion”. This brings up a second window showing the particle motion for the data shown in the main SeisGram2K window, to change the amount of data shown in the particle motion plot (for example to plot a single phase arrival), edit the view in Seisgram2K and re-plot the particle motion.

The particle motion plot is interactive, to change the view either hold down the left mouse button and drag the cursor around the screen, or by use the buttons on the right-hand side.

You can ‘play’ the ground motion through time by using the buttons under “animation” in the bottom left corner.

Picking phases

To pick an arrival manually click on the “pick...” button, which puts the SeisGram2K data window into pick mode. Now if you click on the data screen a green line appears indicating

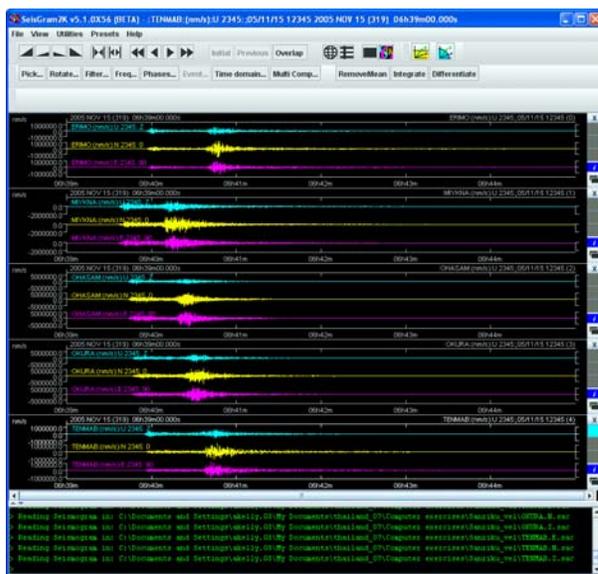


Figure 3 Example of multiple 3-component stations

the time of your provisional pick. The pick can be moved by clicking elsewhere or by holding down the mouse button and dragging. Uncertainty can be added to the pick by holding down the mouse button and dragging upwards.

Once the provision pick is in the correct place the pick can be named and saved using the



menu:

- The pick menu is closed by clicking on the “X” on the left.
- The pick can be removed using the “Clear” button.
- For P phases the pick can be classified as emergent, impulsive or uncertain by clicking on the “e”, “i”, or first “?”.
- The pick can be named by either typing the phase name into the white box to clicking in the arrow to the right of the second “?” and choosing the phase.
- For P phases the arrival can be classified as compression (upwards first motion), dilation (downward first motion), or uncertain using the “c”, “d”, or third “?”.
- The provisional pick can then be saved by clicking on “Set”. The pick line then turns orange.
- All save picks can be removed using the “Del All” button. An individual saved pick can be removed by clicking on the phase name above the orange line and then clicking on the “clear” button.

There are also several automatic picking options:

- **0-P_max** automatically picks the highest amplitude on the selected trace.
- **P-P_max** picks the maximum and minimum amplitude peaks with a separation of no more than 0.8 seconds.
- **StaLta** is a basic short-term-average/long-term-average automatic picker or event detector.

Filtering

There are several options for filtering the data to highlight or remove certain frequencies:

1. The most simple is to use the preset filter options, from the “Presets” menu;
2. Customized filters can be designed in the menu accessed by clicking on the **Filter...** button.

Rotating components

The horizontal data are plotted as the North and East components of the seismogram; however, it is possible to simulate the seismograms that would have been recorded with components rotated to other orientations. For example, if the earthquake location is known it can be useful to plot the data in radial (i.e. one component orientated to point towards the earthquake epicenter) and transverse (i.e. 90 degrees to the radial) rotations, as this highlight differences between some phases.

To rotate the horizontal components, click on the **Rotate...** button to open the Rotate submenu. Then rotate the North component by either typing the desired angle into the

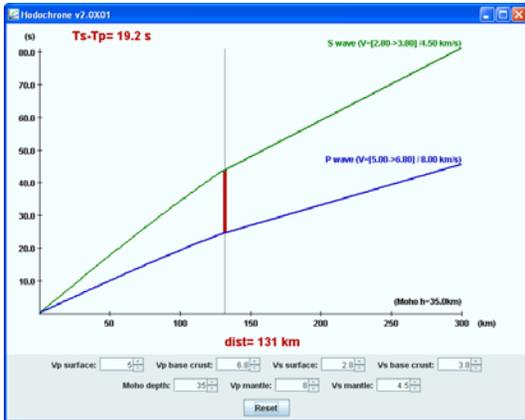


Figure 4 Calculation of epicentral distance in SeismGram2K

the pick information, which is recorded in the box or green text at the base of the screen. Once the difference in time between the S and P arrivals is calculated clicking on either of the buttons above will open a new window with S and P travel time curves. Clicking anywhere on these curves brings up the S-P time in the window. The correct S-P time must be found manually, and the epicentral distance can then be read off the lower axis (Figure 4).

white box, or clicking on the buttons. The East component will automatically rotate to remain at 90 degrees to the North component.

Calculating epicentral distance

If P and S arrivals have been picked, the



buttons can be used to calculate epicentral distance. The button with a yellow background is used for local events and the button with a blue background for more distant ones. To calculate the epicentral distance the time between the P and S picks is needed, this can be taken from