

EPS 20: Earthquakes

Laboratory Exercise 4

Seismicity of Northern California

Purpose: Learn how we make predictions about seismicity from the relationship between the number of earthquakes which occur and their magnitudes.

Background: The Number of Earthquakes

We know that there are more small earthquakes than large ones. If we can identify a pattern, and if we can express the pattern quantitatively, we can use the pattern to tell us what we might expect in terms of the sizes and numbers of earthquakes to come.

Let us consider one particular region of the world and one particular time interval. We can use the magnitude M as a measure of the size of an earthquake and count them. For some particular magnitude M , we will find there are n earthquakes. For a different magnitude, we will find a different value of n . n will be bigger for small earthquakes than for large ones. We say: n is a function of M and write:

$$n(M) = \text{number of earthquakes with magnitude } M$$

As you would expect, the exact value of n for any particular magnitude depends on the length of time for which the count is made. To avoid this, we usually normalize n by the number of years for which we have counted (like a batting average). This gives us a new definition of n

$$n(M) = \text{number of earthquakes with magnitude } M \text{ per year}$$

This measure of the number of earthquakes still has some problems. For example, it depends upon how accurately the magnitudes are measured and how precisely they are tabulated. For instance, the $n(M)$ values will be different if earthquake magnitudes are given to the closest 0.5 units of magnitude or the closest 0.1 units of magnitude.

A better way to express the number of earthquakes is to use the cumulative number of earthquakes,

$$N_c(M) = \text{number of earthquakes per year with magnitude greater than or equal to } M.$$

This measure of the number of earthquakes is much less sensitive to the way the data are saved. Note that the number $\mathbf{N}_c(\mathbf{M})$ is also normalized by the length of time used and is given as the number of earthquakes per year.

For several areas in the world, scientists have graphed $\mathbf{N}_c(\mathbf{M})$ and have discovered that there is usually a very simple relationship between $\mathbf{N}_c(\mathbf{M})$ and \mathbf{M} . Specifically, when $\log_{10}[\mathbf{N}_c(\mathbf{M})]$ is plotted versus \mathbf{M} , the data fall nearly on a straight line. The graph for a straight line is

$$y = \mathbf{A} + \mathbf{b}x,$$

where x and y are variables (the axes), \mathbf{b} is the slope of the line and \mathbf{A} is the intercept of the line with the y -axis. So if we plot $\log_{10}[\mathbf{N}_c(\mathbf{M})]$ versus \mathbf{M} and get a straight line, it suggests that we can write

$$\log_{10}[\mathbf{N}_c(\mathbf{M})] = \mathbf{A} - \mathbf{b} \cdot \mathbf{M}$$

where \mathbf{A} and \mathbf{b} are constants ($-\mathbf{b}$ means the line slopes downward to the right). Here \mathbf{A} is the intercept of the earthquake occurrence curve at magnitude zero (remember, this does not mean "no earthquake", magnitude zero means a relative amplitude of "1" in the measurement that is the basis for the magnitude scale). The value \mathbf{b} is the negative slope of the line. It describes how many more small earthquakes there are for a given number of large earthquakes.

Using this formula it is very easy to characterize the seismicity of a region. We

- (1) define a region,
- (2) pick a time interval,
- (3) count the earthquakes for each magnitude \mathbf{M} in the catalog for the region,
- (4) calculate $\mathbf{N}_c(\mathbf{M})$,
- (5) plot $\mathbf{N}_c(\mathbf{M})$ versus \mathbf{M} , and then
- (6) estimate the parameters \mathbf{A} and \mathbf{b} .

By this process we can summarize the seismicity of a region using just two numbers. The number \mathbf{A} gives an estimate of the general level of seismicity for the region: how many earthquakes of any size (greater than 0) can we expect in the region during the course of the year. The number \mathbf{b} tells us about what magnitudes we can expect. How many of those earthquakes will be big, or how often will big (or really big) earthquakes occur? For most regions, we have found that the number \mathbf{b} is very close to 1.0. That means

that if there are 100 earthquakes with $M \geq 5$, on average, there will be 10 with $M \geq 6$.

We must be cautious applying this method to characterize the number of earthquakes in a region.

1. The results depend upon the type of magnitude used to define the relationship. Most magnitude scales saturate at high magnitudes. When saturation magnitude is reached, this analysis breaks down. Remember, the surface wave magnitude M_S saturates at higher magnitudes than both body wave magnitude m_b and local magnitude M_L , so it is generally better to use the surface wave magnitude scale, particularly for analyses of global seismicity, where large magnitudes are involved.
2. We also have to worry about what happens at low magnitudes. This method assumes that we have done a good job of counting **all** the earthquakes of a given magnitude that occur. But as the magnitude decreases, we eventually reach a point where the earthquake count is incomplete because we cannot detect and report **all** of the earthquakes of that magnitude. Then the analysis also breaks down. This deficiency in the method can actually be used to extract additional information. If we assume that the linear relationship between $\log_{10}[N_c(M)]$ and M is true, then the point at low magnitudes where the tabulated data begins to deviate from the straight line can be used to estimate the lowest magnitude for which we detect **all** of earthquakes.

Procedure:

A. Earthquakes in Northern California

Northern California is a convenient region for checking the relationship between the number of earthquakes and their magnitudes described above. The earthquake catalogs for this region are available on the web page of the Northern California Earthquake Data Center (NCEDC, <http://www.ncedc.org>) which is hosted here at Berkeley. This catalog lists all earthquakes that have been recorded and located in the region with their magnitudes. In the NCEDC catalog, the magnitudes for local and regional earthquakes are given as M_L , the local magnitude. For this lab, you will calculate the cumulative number $N_c(M)$ using the magnitudes listed in the NCEDC catalog.

For this exercise you will estimate the statistics of earthquake occurrence in Northern California by using the data tabulated in NCEDC for one year. When you select a year to analyze, you should choose a year when there was no earthquake with many aftershocks. If the year is dominated by an aftershock sequence, then you will learn more about the statistics of this

particular aftershock sequence than about the statistics of northern California, so avoid Oct 1989 to Oct 1990 – the Loma Prieta Earthquake.

A1. Select one year available in the catalog (1984 – present, it does not have to be a calendar year – it could be from your birthday, 1995, to your birthday, 1996) and use the region from 124.5 W to 120.0 W and 36.0 N to 42.0 N. Count the number of earthquakes in the magnitude ranges 2.0-2.49, 2.5-2.99, 3.0-3.49, 3.5-3.99, 4.0-4.49, etc, up to at least 7.0. For each magnitude range, print the first page (**only the first page!**) of output from the NCEDC for each request and submit it with the assignment.

Use the NSCN catalog on the NCEDC web page:

<http://www.ncedc.org/eps20/>

You will need to tell the search engine the time period and the area you are interested in investigating. Read the instructions, and select the following choices:

Input dataset: NCSN catalog (1967-present)
Give the start and end dates for one year (follow the example format)
Min magnitude: 2.0
Max magnitude: 2.49
Min latitude: 36
Max latitude: 42
Min longitude: -124.5
Max longitude: -120

Use only earthquakes with reported magnitudes.

If you have problems figuring out what to enter, look at the instructions on the web site.

A2. Make a table with the magnitude range, the number of earthquakes in each range, $n(M)$. For each magnitude range, calculate the cumulative number of earthquakes, $N_c(M)$ and include it in the table.

A3. Draw a histogram of the values of $n(M)$ listed in the table.

A4. Plot $\log_{10}[N_c(M)]$ versus M on graph paper. Fit the points with a straight line and determine the parameters A and b .

A5. How and why did you pick the section of the data on the graph which you used to decide where the straight line belonged?

B. Recurrence Intervals

The parameters A and b you calculated in section **A** provide a useful characterization of the seismicity of a region. We can use them to estimate the rate at which future earthquakes will occur in the region we studied. One common way to express this rate is the **recurrence interval** for earthquakes of a given magnitude. We define this as

$RI(M) = \text{average time between earthquakes with magnitudes greater than or equal to } M.$

This is the same as

$$RI(M) = 1 / N_c(M)$$

(remember, N_c is normalized to "the number of earthquakes per year" or earthquakes/year. So when we take the inverse, we get years/earthquake). If we know the parameters A and b for a region, we can calculate the value of $N_c(M)$ for any magnitude M , and calculate $1 / N_c(M)$ to estimate the recurrence interval.

We can use this procedure to estimate recurrence intervals. For example:

- 1) We can extrapolate to small magnitudes where detection is incomplete and estimate how often earthquakes of that size may be occurring.
- 2) We can use it to extrapolate to large magnitudes, for events which seldom happen and estimate approximately how long we might have to wait for the next earthquake of that size or larger. Note that when using the linear relationship between $\log_{10}[N_c(M)]$ and M to extrapolate in magnitude, we are making an important assumption: that the relationship is valid over the entire magnitude range.

B1. On the plot of N_c add the values for A and b you calculated in part **A**, find the average recurrence intervals for earthquakes of magnitude 2, 5, and 8 in northern California.

B2. Use the recurrence intervals you calculated in B1. How many earthquakes with magnitude 2 or greater do you expect in Northern California in one day? If the last magnitude 5 earthquake in Northern California occurred on Dec. 22, 2002, when do you expect the next one? How about the next magnitude 8 earthquake, given the fact that the last one was in 1906?

B3. Your analysis was performed using data from only one year. How can you get more reliable estimates of recurrence intervals?