Earthquakes and the Richter Scale

Read-ahead

Introduction

The quick and accurate detection of an earthquake is important both for coordinating emergency response, and for monitoring fault lines. In the United States, the National Earthquake Information Center processes data from a global seismograph network to quickly determine the location and magnitude of an earthquake. Similar centers exists around the world. In this set of problems we will explore how the Richter scale is used to quantify the energy released by an earthquake, and also see how the two main types of seismic waves can be used to pinpoint an earthquake's epicenter.

Figure 1: Toppled buildings in Taiwan (1999).

Figure 2: Road damage.

Instructions

After reading through *Earthquake* context and questions below, you should complete the pre-read assignment in Canvas. Note: *you will have a chance to talk further with your coach before answering the questions below in detail.* The point of pre-read is to "prime the pump" for further conversations with your coaches.

Earthquakes and the Richter Scale

In 1935 Charles Richter and Beno Gutenberg defined the *magnitude* of an earthquake by the equation

$$M = \log_{10}\left(\frac{W}{W_0}\right),$$

where W is the intensity (strength) of the earthquake, and W_0 is the intensity of the threshold quake in a given region.

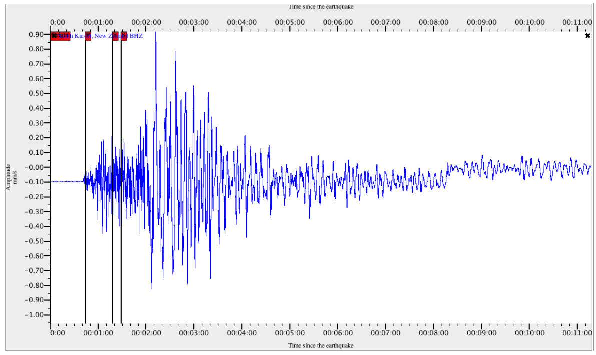

Figure 3: Seismogram of New Zealand earthquake (2011).

The *energy* E (measured in ergs) of the earthquake is then modeled by the equation

$$\log_{10}(E) = 11.8 + 1.5M.$$

Questions

1. Suppose an earthquake is detected with intensity $W = 200W_0$. What is the magnitude of this earthquake on the Richter scale? Round your answer to one decimal place.
2. Suppose we want to compare the magnitudes of two earthquakes, the first with magnitude M and intensity W, and the second with magnitude N and intensity X. Assuming that the threshold intensity W_0 is the same in both locations, use the Richter equation $M = \log_{10}\left(\frac{W}{W_0}\right)$ to write an equation giving the difference $M - N$ in the the magnitudes of the two earthquakes in terms of their intensities W and X. Write your answer as an equation of the form "$M - N =$ ...", and use "log" for "$\log_{10}$". The threshold intensity W_0 should not appear in your equation.
3. The San Francisco earthquake of 1906 registered a magnitude of 8.3 on the Richter scale. A South American earthquake later that year registered a magnitude of 8.9 on the Richter scale. How many times greater than the intensity of the San Francisco quake was the intensity of the South American earthquake? Round your answer to one decimal place.
4. What was the energy of the San Francisco earthquake? Enter the power of 10 in the answer box. Round your answer to one decimal place.
5. A 15-second shake in San Diego was measured on the San Andreas fault line to have an energy of about 1.0×10^{18} ergs. What was the magnitude of this earthquake? Round your answer to one decimal place.

In the remaining questions, we will explore how seismographs can be used to pinpoint an earthquake's location. Primary waves (P-waves) are compressional waves that are longitudinal in nature. P-waves travel faster than other waves through the earth to arrive at seismograph stations first, hence the name "Primary". These waves can travel through any type of material, including fluids. Secondary waves (S-waves) are shear waves that are transverse in nature. S-waves can travel only through solids, as fluids (liquids and gases) do not support shear stresses. S-waves are slower than P-waves, and speeds are typically around 60% that of P-waves in any given material.

6. Let A and B be two seismic stations, with station B 1000 km due east of station A. An earthquake occurs somewhere (not necessarily on the line between A and B) and station A

detects P- and S-wave arrivals separated by 1 minute, and station B detects P- and S-wave arrivals separated by 2 minutes. Assume P-waves travel at 4.8 km/s and S-waves travel at 3 km/s. How far apart is the epicenter of the earthquake from station A? Round your answer to the nearest integer.

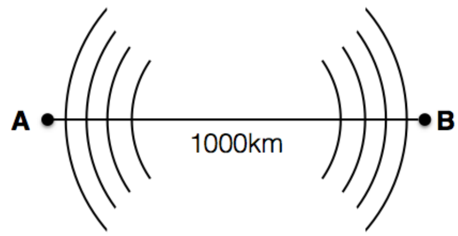

Figure 4: Seismic waves arriving at stations A and B.

7. How far away from the earthquake is station B? Round your answer to the nearest integer.
8. (Graded for completeness only.) Explain why, given the information in the problem, there are two possible locations of the earthquake.
9. Suppose a third station, located 909 km due north of station A, detects the waves separated also by 1 minute. Without doing any calculations, which of the two possible locations is the epicenter likely to be?
10. Consider the following diagram, where C is the epicenter, b is the distance you computed in Question 6 and a is the distance you computed in Question 7.

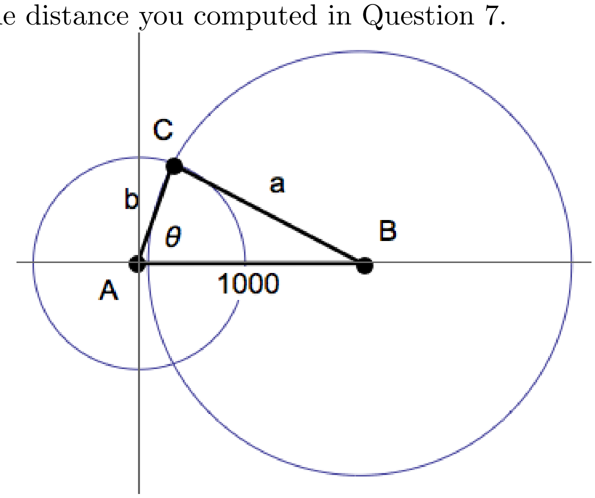

Figure 5: Locating the epicenter.

Use the "Law of Cosines" $c^2 = a^2 + b^2 - 2ab\cos\theta$ to find the angle θ from due east (in degrees) that one would need to travel at starting from station A to reach the epicenter of the earthquake. If the angle is north of east use a positive value, and if the angle is south of due east use a negative value. Round your answer to two decimal places.

Instructions, part deux

After reading and reflecting on these questions, complete the pre-read assignment on Canvas. This will give your coach some insight on your thinking in order to best help you before you are required to formally answer these questions.