EART119 – HW#4
Data Analysis: Aftershock decay rates and power-law fits

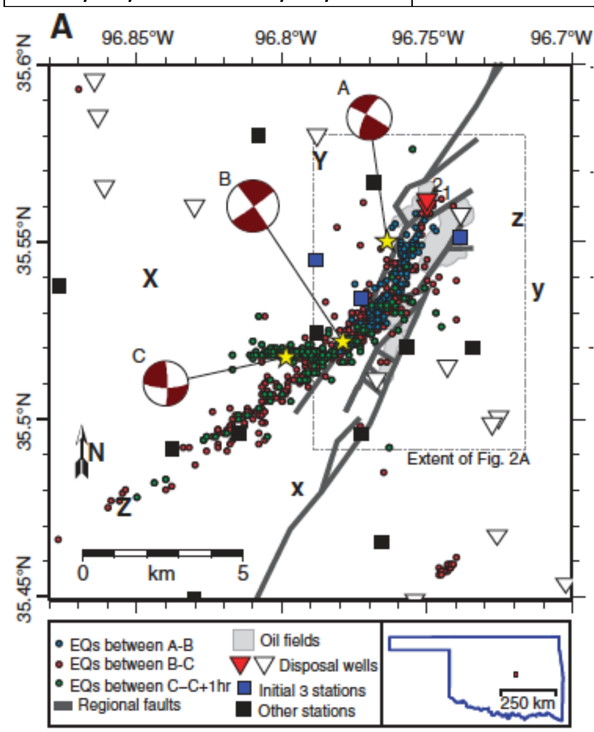
The vast majority of earthquakes are aftershocks, i.e. earthquakes that are caused by stress perturbations of preceding events. Thus, the study of aftershocks is of key importance in seismology and provides a critical component for operational earthquake forecasts and short-term hazard assessments. Aftershocks are special in the sense that the average expected rate is well described by an empirical relationship called Omori's law:

$$\mathrm{d}N/\mathrm{d}t = K/(c+t)^p$$

where $\mathrm{d}N/\mathrm{d}t$ is the event rate after the mainshock, *t* is time after the mainshock, and *K, c* and *p* are constants describing the general productivity and decay rate of the aftershock sequence. This empirical relationship provides the opportunity to predict the average expected rate of earthquakes from hours to months after a mainshock.

Consider the record of seismic events within the central U.S., constrained be the following parameters:

Time range	MAG range	Longitude in °	Latitude in °
2010/01/01 to 2012/12/31	2.5 to 7	-100 to -95	34.3 to 37



Exemplary figure of the M5.7 Prague earthquake as well as fore and aftershocks in map view. The mainshock is highlighted by the yellow star and focal mechanism labeled by the letter B. Two additional M5 events are labeled A and C.

Figure from: Keranen, K.M., Savage, H.M., Abers, G. a., and Cochran, E.S., 2013, Potentially induced earthquakes in Oklahoma, USA: Links between wastewater injection and the 2011 Mw 5.7 earthquake sequence: Geology, v. 41, no. 6, p. 699–702, doi: 10.1130/G34045.1.

Download:

1. Download the earthquake catalog from: http://www.ncedc.org/anss/catalog-search.html, using the above specified parameters (you can also go to: https://earthquake.usgs.gov/earthquakes/search/). You can either go to the website

and input the parameters manually or you can use the python model os.system and the bash command ‘wget’. Alternatively, you can work with the slightly cleaner data file (‘prague_aftershock_clean.txt) which is on Canvas.

Initial data processing: **(20 points)**

2. Write a script that imports the earthquake catalog! This is a nice exercise because you are dealing with somewhat messy data that includes date strings, time strings, magnitude type and regular floating point numbers. You can focus on loading the first 6 columns (Date to Mag). Useful commands for this exercise are numpy.loadtxt, numpy.genfromtxt and standard ASCII file imports with file_obj = open([file_name], ‘r)

   On Linux and Mac you can also use the bash function: >>sed –e ’s/[replace]/[with]/g’ [old_file] > new_file which allows you to search and replace anything in ASCII files.

   I recommend using numpy.genfromtxt.

3. Select the data of interest:
   a. Identify the M5.7 Prague main-shock in 2011
   b. Select the area of interest using the following equation:

$$R_{\max} = 10^{(0.25M - 0.22)}\ [\mathrm{km}]$$

From: Gardner, J.K., and Knopoff, L., 1974, Is the sequence of earthquakes in southern California, with aftershocks removed, Poissonian? Bull. Seismol. Soc. Am, v. 64, no. 5, p. 1363–1367.

You can project the data from spherical into Cartesian or into an equal distance projection using matplotlib basemap. The easiest way might be to directly use the haversine formula to compute distances between your lon/lat vectors (https://en.wikipedia.org/wiki/Haversine_formula)

   c. Select only events after the mainshock
   d. Convert date-time to days relative to the mainshock occurrence
      $t_{as} = t_{eq} - t_{MS}$, where t_{as} are the aftershock times relative to the mainshock, t_{MS}

Aftershock rates and rate-decay fitting: **(20 points)**

4. Compute the aftershock rate decay using the following equation for statistical density estimates:

$$\mathrm{d}N/\mathrm{d}t = k/(t_{i+k} - t_i);\ for\ i = 1 \text{ to } n\text{-}k$$

   where k is the sample size with higher values of *k* resulting in smoother density estimates, and t_{i+k}-t_i is the distance between the ith and the i+kth event. This is essentially a sliding sample window from your first to your n-kth event with a step size of 1.

See: Silverman, B.W., 1986, DENSITY ESTIMATION FOR STATISTICS AND DATA ANALYSIS: Monographs on Statistics and Applied Probability, p. 1–22.

5. Compare the temporal decay from the above equation to a simple histogram of events after the mainshock! What are some advantages of using statistical density estimates vs. a binned representation of the data?

6. Fit the power-law portion of the time decay using

$$\mathrm{d}N/\mathrm{d}t \sim t^p$$

Note that there are several steps involved in determining the fit, including (i) log-transformation of the data, (ii) selecting the correct time range over which the data shows power-law behavior and (iii) finally determining the fit in a least squares sense.

7. Plot the determined fit and the data on double logarithmic scales! Report the aftershock decay exponent, *p*, and the R2-value.