Homework – Computational Geosciences
Week 02 – *Excel goal-seek*

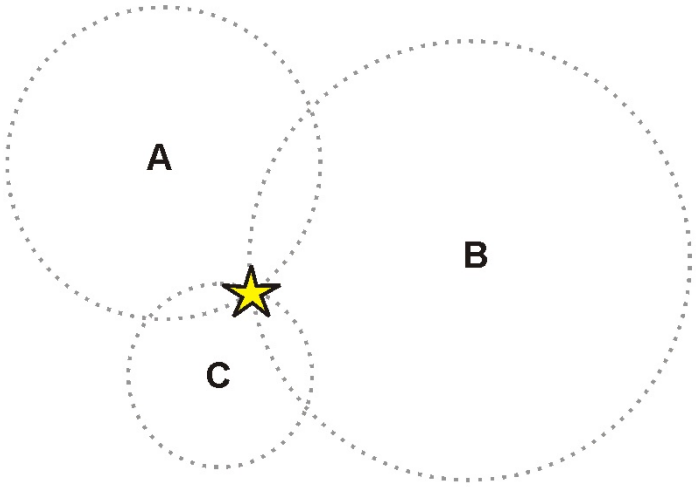
Locating earthquake epicenters: In this exercise you will estimate the location of an earthquake epicenter using Excel's Goal Seek.

P-waves always travel faster than S-waves, and we use the difference (Ts-Tp) in their arrival times and known velocities to determine the distance to the epicenter.

Ts-Tp=x/Vs – x/Vp, where x is the distance to the earthquake. Thus:

x=(Ts-Tp)*(Vs*Vp)/(Vp-Vs)

Given a number of determinations of the distance from various seismic observatories (such as stations A, B and C below), we can find the point on the Earth's surface that is the appropriate distance away from each of the observations.



To find the solution we will use Excel's Goal Seek tool.

1) **Setup a spreadsheet similar to the one below**, showing the lat/longs for 5 stations with their corresponding Ts-Tp values. These Ts-Tp values are shown below, and we will use Vp and Vs values of 6 and 4, respectively:

	A	B	C	D	E	F	G	H	I	J	K	L
1			Epicenter guess:		Latitude	Longitude						
2	Given						degrees					
3	Vp (km/s)=	6					radians					
4	Vs (km/s)=	4										
5												
6	*Seismographs at:*											
7	Long(dg)	Lat(dg)	Ts-Tp	x(km)	Long(rad)	Lat(rad)		dist(rad)	dist (km)	diff(km)^2		
8	-110	41	46.82									
9	-110	43	28.57									
10	-110	52	55.93									
11	-114	51	49.85									
12	-116	39	73.27									
13									SSE		minimize this	

2) Use the above equation for distance to earthquake to **fill out the x(km) column, and then convert Longs and Lats to radians**.
3) Now you have to make a decent guess as to where the earthquake location is. **Make a 2D plot of the lat/longs of the stations**, and use the distance values (x) to estimate by eye the coordinates of the epicenter. Enter your guess in the Epicenter guess section. Put the 2D plot in a separate sheet.
4) Based upon this guess, we can calculate the great-circle distances (i.e. distance over the surface of a sphere) between the proposed epicenter location and each station. To do this, use the following equation:

$$\Delta\theta = \arctan\left\{\frac{\sqrt{\left[\cos\phi_2 \sin\Delta\lambda\right]^2 + \left[\cos\phi_1 \sin\phi_2 - \sin\phi_1 \cos\phi_2 \cos\Delta\lambda\right]^2}}{\sin\phi_1 \sin\phi_2 + \cos\phi_1 \cos\phi_2 \cos\Delta\lambda}\right\}$$

Where ϕ_1, λ_1 and ϕ_2, λ_2 are the latitude and longitude of the two points, respectively, and $\Delta\lambda$ is the difference in longitude, and $\Delta\theta$ is the angular distance between the two points. Remember the distance in kilometers is then $r^* \Delta\theta$, where r is the radius of the Earth (~6371 km). **Use this formula to fill out the dist(rad) and dist(km) boxes**. Rather than try to enter this formula into one cell (huge!), divide the formula into a number of separate terms – each with their own cell – and combine them together in another cell.

5) Goal Seek will vary the values of one cell (e.g. latitude or longitude of epicenter) to minimize the values of another cell. So we need to establish a cell which holds a statistic that needs to be minimized. In this case (and many other examples) we will want to minimize the sum of the squares (SSE) of the differences between the measured distance to the epicenter (i.e. x) and the calculated distance to the epicenter. The calculated location (lat,long) of the epicenter will change as Goal Seek updates the solution. Thus, we can use Goal Seek to perfect our initial guess. **Calculate the difference between the known distance (x) and the distance using our proposed epicenter – then square this value and enter it in the spreadsheet (diff(km)^2)**. The SSE is simply then the sum of this column.
6) What we want to do is minimize the statistic SSE to get the location of the epicenter. In this case we would want to use Goal Seek to set our SSE cell to zero by changing

the location of our initial guess for the location of the epicenter. Thus we would minimize SSE by letting Goal Seek vary either latitude or longitude. Goal Seek will only vary one cell at a time so you will have to use it a number of times to get a final solution. Do several iterations alternating between latitude and longitude of the epicenter. If Goal Seek goes kaput (i.e. finds NANs), you just have to choose a different guess for the epicenter – sometimes you just have to change the guess a hair.

7) Your final SSE should be very small – i.e. you can get it much less than 10 with sufficient playing.

Questions to answer:

1) In a few sentences summarize how the process of finding the epicenter went.
2) In a few sentences, discuss some advantages and disadvantages of using a tool like this.
3) Can you think of any other geoscience applications where Goal Seek might be necessary?

What to hand in: Email me a) the spreadsheet with your best SSE, and b) a PDF document with your answers to the above questions.

This homework is based upon an assignment by Steve Sheriff, Univ. Montana