Geov112 - Exercise Set 3 (Deadline: 22 September 2017)

These exercises cover Chapters 3-4 from McMahon and parts of Paragraphs 4.2-4.4 and Appendix 1 from Fowler. From now on the exercises will be more focused on geophysics and not so much on Matlab or mathematics. The two areas of geophysics that are applied in this exercise set are Global Seismology and Seismic Exploration. Remember to use pen and paper, to ideally write the complete program, but at least make a sketch of the program, before you start typing in the programs. This is good programming practice and also useful practice for the quizzes and the exam.

Learning Outcomes for Exercise Set 3
In this exercise set you will:

1. Get to apply most of the Matlab programming concepts from the 2 previous exercise sets to simple geophysical problems

2. Learn what spherical and geographical coordinates are and how they can be used to compute epicentral distances

3. Use Matlab to download a 1D global velocity model, plot this model and explain its main features

4. Use Matlab to compute travel times and amplitudes for a simple layer over halfspace velocity model

5. Use Matlab to plot seismic velocity models in 2D and 3D.

1. **Review question for McMahon Chapters 1 and 2**
   (a) Give the first three non-zero terms of the Taylor expansion of the sin function around 0. (This is not a Matlab question! Also, please let us know if you have not had Taylor expansions before.)
   (b) Plot in one figure the sin function and the first, third and fifth order Taylor expansion between 0 and 2π/the second and fourth order terms are zero). Make sure you use enough points to compute the different lines. Also use different line types and a legend.
   (c) Explain in your own words what you see in the figure.
2. **Statistics and Random Numbers.**
   (a) Use the `rand` command to generate 20 random numbers between 0 and 1. Compute the average and standard deviation. Plot the numbers in a histogram with increments of 0.1. (Note: there is no need to generate this answer, a list of numbers, in your pdf file; only give the Matlab commands. The same holds for the other questions in this exercise.)
   (b) Do the same for 200 numbers.
   (c) Do the same for 2000 numbers.
   (d) Discuss the results of the above exercises.
   (e) Use Matlab to generate and plot 150 random numbers between 0 and 20.
   (f) Use Matlab to generate and plot 100 random numbers between -10 and 10 and plot these numbers.

3. **McMahon Matlab exercises** Do exercises 4 and 5 of chapter 3 and exercise 1 of chapter 4.

4. **Spherical and Geographical Coordinates**

   (a) (This question refers back to exercise 8 of the 2nd exercise set on polar coordinates.) In most cases the conversion between polar coordinates and Cartesian coordinates works well in the sense that for one Cartesian point there is only one corresponding point in polar coordinates and the other way around (in mathematics the 'map' between polar and Cartesian coordinates is called a bijection). However, there is an exception. Which exception is this? Is this exception very important in the Earth sciences?

   (b) If you know the spherical coordinates (r, ϕ, θ) of a point then give the formulas that compute its Cartesian coordinates (x, y, z).

   (c) If you know the Cartesian coordinates of a point then give the equations that compute its spherical coordinates.

   (d) Explain the difference between spherical coordinates and geographical coordinates. In this course we denote geographical coordinates by (r, ϕ, θ').

   (e) Give the equations that convert spherical coordinates to geographical coordinates.

   (f) Give the equations that convert geographical coordinates to spherical coordinates.

   (g) Give the equations that convert Cartesian coordinates to geographical coordinates

   (h) Give the equations that convert geographical coordinates to Cartesian coordinates.

   (i) Below is a list of places on the Earth. Assume that the Earth is a sphere with radius 6371km. On the internet you can find the geographical coordinates of these places. In this question you are asked to give the location in spherical and Cartesian coordinates (use arrays for your computations!). Assume that all places, except for the last one, are exactly on the surface of the Earth. The places are:

      i. the North Pole
      ii. the South Pole
      iii. a point on the equator
      iv. Realfagbygget in Bergen
      v. Manila (the Philippines)
      vi. Bogota (Colombia)
      vii. New York City (US)
      viii. Beerenberg volcano on Jan Mayen
      ix. the top of The Jungfrau (a nice mountain in Switzerland; use the elevation!)

5. **Global Seismology I: Epicentral Distance** This question uses the previous exercise. Suppose we have two points on the surface of the Earth. The shortest traveling distance (i.e. by staying on the sphere) between these points can be computed by using the definition of the inner product. Express this distance in terms of the geographical coordinates of these two points. (Note: a great circle of a sphere is a circle on the sphere that cuts a sphere in two equal halves. The shortest traveling distance between two points on a sphere is the length of the shorter ('minor') arc of the great circle.)

(a) The angle between the two vectors that denote two points on the Earth is called the angular distance (unit in degrees or radians). If an Earthquake happened in one of these points then the angular distance is called the epicentral distance. Write a Matlab script that computes the epicentral distance between two points located on Earth.

(b) Last year there was a relatively big earthquake with magnitude 5.3 in Svalbard (Spitsbergen). What is the epicentral distance of this earthquake when you are in Bergen? (You may use the location of Longyearbyen here, though this is not exactly where the earthquake happened.) Information on this earthquake can be found in:
www.spitsbergen-svalbard.com/2016/03/30/earthquake-in-longyearbyen.html

(c) Compute the straight line distance between Longyearbyen and Bergen.

(d) Assume that the P-velocity between Longyearbyen and Bergen is constant at 8.4 km/s and the S-velocity is 4.2 km/s. What is the travel time of the P-wave and S-wave from this earthquake recorded in Bergen?

(e) Give the geographical coordinates of Longyearbyen and Bergen and the P-wave and S-wave velocities. If you have not already done so in (b) and (d) then give the Matlab commands that compute the epicentral distance and the travel times of the P-wave and S-wave.

(f) Compute the epicentral distance between San Francisco and Bergen and repeat the computation of the travel times.

6. **Global Seismology II: 1D structure of the Earth.** The main layers of the Earth are the crust, the upper mantle, the lower mantle, the outer core and the inner core as we have already seen. In this exercise you will plot a velocity model of the Earth that is more detailed than before. In global seismology the velocities are given as a function of spherical or geographical coordinates. The simplest velocity models only depend on one variable (the distance). These models are therefore called 1D models.

   (a) Download the file iasp91.txt from miside and save it in the directory where you do these Matlab exercises. This file contains what is called the IASP91 (pronounced 'Yas-P 91') model. Open iasp91.txt, study its contents. Write a Matlab script that reads the IASP91 velocity model (hint: use the commands `fid = fopen('iasp91new.txt');` and `iasp91 = textscan(fid,'%f%f%f%f');` look in the examples on the help page for `textscan` for details. This creates a cell with the name `iasp91`. You can extract the columns by typing `iasp91{1}` etc.

   (b) Plot the velocities and densities in one figure using the `plotyy` command. Again do not forget the labels on the axes.

   (c) Compute the average P-velocities and the standard deviations for the 5 main layers. Then do the same for the S-velocities and plot this information in a histogram using `subplot` (4 figures total).

   (d) Comment on the results.

7. **Exploration Seismics and Regional Seismology I: Waves in a Layer over a Halfspace**

   (a) One of the simplest models used in seismics consists of a layer over a halfspace (as you have seen in Geov111). In Exploration Seismics this layer could be the water layer or sedimentary layers and the halfspace would be the bedrock. In Regional Seismology this layer often is the crust and the halfspace the upper mantle. We will study this layer over halfspace model in this exercise. Assume that the thickness of the layer is 5 km (e.g. sediments) and the P- and S-velocities are 5.2 km/s and 3.1 km/s respectively. The velocities in the halfspace are 8.1 km/s and 3.9 km/s. Also assume that a source (for example an earthquake or an explosion) is at the surface and a seismograph is also at the surface. Draw a sketch of this model (include the thickness and velocity values) and indicate the direct wave, the reflected wave and the refracted wave.

(b) Assume that there are seismographs (also called stations or receivers) at 10 km - 25 km from this source with a spacing of 1.5 km. Use Matlab to compute the travel times of the direct P-wave and the reflected P-wave.

(c) Use Matlab to compute the relative amplitude of the direct and the reflected P-wave from this source to the receivers (remember amplitude decays as 1/distance in 3D so the relative amplitude of the direct wave at the first station would be 1/10.

(d) Plot the velocity model (velocity versus, the traveltimes and amplitudes of the direct and reflected waves (use the `subplot` command; one figure shows the velocity model, the second the traveltimes, the third figure the amplitudes). Do not forget the labels of the figures.

8. **Seismic Exploration and Regional Seismology II: Seismic Exploration and 2D Plotting.** Valhall is an oil field located in the Norwegian part of the North Sea. In the literature a highly simplified P-velocity model of the area around Valhall can be found. It is given by:

$$v(z) = 1.55 - 0.48z \tag{1}$$

Here z is the vertical coordinate in km (note that depth is negative!) and v is the velocity in km/s.

(a) Plot this velocity model between 0km and 2km in a 1D plot.

(b) A slightly more complicated model is given by adding an extra term to this velocity:

$$v(z) = 1.55 - 0.48z - 0.8e^{-(z-z_0)^2/r_0} \tag{2}$$

Plot this model for $z_0 = -0.6km$ and $r_0 = 0.3km$.

(c) The above models can also be plotted in 2D and 3D. We will first plot the models in 2D. Create a meshgrid with x-coordinates between 3.5km and 5.5km and z-coordinates between 0km and 1.5km. Use a grid spacing in the x-direction of 20m and in the z-direction of 10m. Extend the above models so they are defined on the meshgrid. Plot the two velocity models in a 2D plot using contour lines.

(d) Also plot the models using `imagesc` (look up the information on this command using the help pages). Add a color bar to this plot (again look up the help pages for details on how to plot colors and color bars). As always, don't forget to label the axes!