Geov112 - Exercise Set 5 (Deadline: 30 October 2017)

1. **Review of plotting of velocity models**

   (a) Create a 2D velocity model that consists of four layers. The first layer has a P-velocity of 4.4km/s, the 2nd layer a P-velocity of 5.5km/s, the third layer has a velocity of 6.6km/s and the fourth layer a velocity of 8km/s. The thickness of the layers is 2km, 5km, 3km and 6km. The horizontal dimension of the model is 40 km. Use a grid spacing in the vertical direction of 100m and a grid spacing in the horizontal direction of 400m.

   (b) Plot this model in four different ways using `subplot`: 1. using `imagesc`, 2. using `mesh`, 3. using `contour` and 4. using a 1D profile of the model at a given horizontal distance.

2. **Seismic Processing - 2D velocity models** Valhall is an oil field located in the Norwegian part of the North Sea. In the literature a highly simplified velocity model of the area around Valhall can be found. It is given by:

$$v(z) = 1.5 - 0.48z \tag{1}$$

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

   (a) Plot this velocity model between 0km and 2km in a 1D plot. Use a spacing of 20m and plot the model in two different ways (this is a review exercise).

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

$$v(z) = 1.5 - 0.48z - 0.8e^{-(r-r_0)^2/r_0^2}, \tag{2}$$

   with $r - r_0 = \sqrt{(x-x_0)^2 + (z-z_0)^2}$. Note that this model is now 2D (in other words the velocity depends on both x and z). Plot this model for $x_0 = 4.6$ km, $z_0 = -0.6$ km and $r_0 = 0.3$ km. 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.

   (c) 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).

   (d) Finally, extract and plot 1D profiles from the 2D model for $x = 3.5$ km and for $x = 4.6$ km.

3. **Seismic Velocity Models**

   (a) Load the Marmousi model in Matlab using `load` (see miside). Plot the Marmousi model with the `reshape` and `imagesc` command (use the manual if you are not familiar with a certain Matlab command; the Marmousi model has size 384x122 (check!) and the dimensions are x=0:dx:9192 and z=-2904:dx:0 with dx=24 meter.). Label the axes.

   (b) Also plot the Marmousi model with the `contour` and `contourf` commands.

(c) Compute the average, minimum and maximum velocity of the Marmousi model (Note: these are typical velocity values found in seismic exploration. The lowest velocities are around 1500 m/s (velocity through water) and the highest around 5000 m/s.)

(d) Plot three 1D depth-velocity profiles of the Marmousi model in one figure using the `stairs` command. Choose three suitable locations for this from the 2D plot. Indicate which horizontal positions you chose for this. Briefly discuss the profiles.

4. **Seismic Acquisition: RAM, Memory and Seismic Data**

(a) The goal of this exercise is to show how quickly computer limitations in terms of memory become a problem in seismics. First check the RAM and Memory of the computer you are working on (RAM stands for Random Access Memory) and is the place where the computer stores data used in computations).

(b) Now create in Matlab a random square matrix of 500 by 500 elements. How much RAM does this matrix use?

(c) What is the largest random square matrix the computer can save in RAM?

(d) If you record seismic traces for 4 seconds with a sampling interval of 1 millisecond then how many of these traces can the computer keep in memory? How many of these traces can be kept in the RAM.

(e) A seismic vessel is towing a source and a cable with receivers. The source is 100 meters behind the vessel and the cable starts at 200 meters behind the vessel. The cable is 8 km long and the receiver spacing is 10 meters. If the vessel 'shoots' every 100 meters over a distance of 20 km how many data are recorded? How much memory does this take? Write a matlab script that has all the previous parameters as input and outputs the number of seismograms.

(f) Use the previous exercise to compute how many traces you can save on your computer's harddisc (i.e. the memory). Also compute how many traces you can keep in RAM. (Comment: in seismic exploration companies shoot not one line (as in this exercise) but many lines. This explains why in seismic exploration powerful computers are needed to process all data.)

(g) In global earthquake seismology a typical sampling rate is 20 milliseconds. The length of a complete seismogram is about one hour (see figures 4.16 and 4.18). How much memory is needed to record one seismogram?

(h) The number of earthquakes recorded every year by a station depends strongly on its location (see table 4.1 on page 115 for a list of the approximate number of earthquakes as a function of the earthquake magnitude). Explain why this is.

(i) Suppose you need to install a seismometer in a remote place where there are a lot of earthquakes (such as an island in the Aegean Sea or somewhere in the Andes) and that you will return to this remote place after one year to collect the data. If the seismometer records continuously for one year and stores all the data locally on a harddisk, then what is the minimum number of gigabytes needed to store all this data?

5. **Exploration Seismics/Regional Seismology IV**

   (a) In exercises 2 and 3 the velocity models were plot as a function of x and z. In general velocity models are also a function of y. Use `meshgrid` to define the velocity model in equation (1) on a 3D grid. Use the same x and z values as in exercise 2 and use y values between -1km and 1km with a spacing of 20m.

   (b) It is not possible to visualize a 3D model completely. However, the Matlab command `slice` makes it possible to plot various slices of this model. Use `slice` to plot this model.

   (c) Do the same for the velocity model in equation (2) but now with

$$r - r_0 = \sqrt{(x - x_0)^2 + (y - y_0)^2 + (z - z_0)^2} \qquad (3)$$

   (As an aside: this document was created using LaTeX and not using Word. Two of the reasons for doing this is that equations look much nicer in LaTeX and they are easier to type. In Geov219 we will give a brief introduction to LaTeX. Look on wikipedia (available in bokml and english) for some more information on LaTex.) Use the slices so that the main features of the model, especially the deviation from a 1D model, are clearly visible.

   (d) Extract a part of the Marmousi model that has the size 30 (in the x-direction) by 60 (in the z-direction). Then extend the Marmousi model in the y-direction (from y=0 m to y=552 m by assuming that $v(x, y, z) = v(x, 0, z)$ for all y. Do this in two different ways: using *repmat* and by using a for loop.

   (e) Plot the 3D Marmousi model using `slice`.

   (f) Do exercise 4b from exercise set 4 (this is another practice in using for loops).

6. **Exploration Seismics/Regional Seismology V**

   (a) In exercise sets 3 and 4 we studied wave propagation in a layer over halfspace model (i.e. we computed ray paths, travel times and amplitudes). We now consider a model with two layers over a halfspace. The layers have a thickness of 6 km and 8 km respectively and velocities of 5.4 km/s and 6 km/s. Compute the traveltimes of rays that start at the surface get transmitted at the first interface, then get reflected at the second interface and then go back up to the surface by transmission at the first interface. Choose an appropriate take-off angle range. (If the lower intereface is the Moho then these rays are denoted by PmP)

   (b) Plot the ray paths of the previous exercise.

   (c) Plot the traveltimes as a function of take-off angle

   (d) Determine for what take-off angle critical reflection at the lower interface occurs. Explain your answer.

7. **Exploration Seismics/Regional Seismology VI**

   (a) The earthquake in Mexico that happened in September 2017 was reported to have a magnitude to of 7.1. In this exercise we will show how this magnitude was determined. Magnitudes are derived from what is called the 'seismic moment'. The seismic moment M_0 of an earthquake is computed by integrating slip along a fault plane:

$$M_0 = \int_{x_1}^{x^2} \int_{y_1}^{y^2} \mu(x,y)|\mathbf{u}(x,y)|dxdy \tag{4}$$

Here, (x, y) is a point on the fault plane, $\mu(x, y)$ is the shear modulus at (x, y), $\mathbf{u}(x, y)$ is the slip at (x, y) and $|\mathbf{u}(x, y)|$ is the absolute value of the slip at (x, y). Therefore, in order to compute the seismic moment M_0, we need to compute μ and $\mathbf{u}$ on each point of the fault plane. We first compute μ. For this we use the values of the shear velocity v_s and density ρ at the (approximate) depth of the fault plane as these determine μ: $\mu = \rho v_s^2$. Look up the approximate depth of the earthquake in Mexico and then determine, using the IASP91 model of exercise set 3, the approximate value of μ in Matlab.

(b) It turns out that μ does not vary a lot along the fault plane so we may assume that it is constant. Therefore, we can take it outside of the integral so that all we now have to compute is:

$$M_0 = \mu \int_{x_1}^{x_2} \int_{y_1}^{y_2} |\mathbf{u}(x,y)|dxdy \tag{5}$$

In order to compute this integral we first need to determine the dimensions of the fault plane. From the USGS (United States Geological Survey) websites
earthquake.usgs.gov/earthquakes/eventpage/us2000ar20#executive
and, in particular,
earthquake.usgs.gov/earthquakes/eventpage/us2000ar20#finite-fault
we find that the fault plane of our earthquake has a size of (approximately) 30 km by 15 km. Here 30 km is along the strike direction (we call this the x-direction) and 15 km in the dip direction (we call this the y-direction). From the variation in the slip direction it seems ok to discretize the fault plane in segments of 200 m by 200 m. Give the Matlab commands that generate a meshgrid for this fault (assume that $x_1 = -20, x_2 = 10, y_1 = -10, y_2 = 5$ (all units in km)). Note that we now that we have these numbers and the spacings Δx and Δy (see above), so that we also have the number of grid points in the x-direction, n_x and y-direction n_y. We need all these in the numerical computation of the 2D integral.

(c) We now need to compute the slip on the fault. The slip is defined as a vector $\mathbf{u}(x, y) = (u_1(x, y), u_2(x, y))$ at each point (x, y). Moreover we see from the picture u_1 is much smaller than u_2 so we can safely assume that it is zero everywhere. u_1 has a maximum in the origin and we assume that it has the form

$$u_2(x,y) = -3e^{-\sqrt{x^2+y^2}/2} \tag{6}$$

and the unit of slip is in meter. Compute u_2 on the meshgrid defined in the previous exercise and plot it using the 'contour', 'mesh' or 'surface' command.

(d) Another way of plotting the slip $\mathbf{u}$ along the fault is using the 'quiver' command. Look up how the quiver command works, compute u_1 and plot the slip using 'quiver'. Make sure that also this plot looks like the plot on the USGS website.

(e) Compute the seismic moment M_0 by integrating the slip along the discretized fault plane:

$$M_0 \approx \mu \Delta x \Delta y \sum_{x_i=1}^{n_x} \sum_{y_i=1}^{n_y} u_2(x,y) \tag{7}$$

Note that, since $u_1 = 0$, we have replaced the absolute value of $\mathbf{u}$ by u_2.

(f) Check whether the seismic moment that you computed is (approximately) the same as what is given on the USGS website.

(g) Once the seismic moment is computed you can easily compute the magnitude using the equation

$$M_w = 2/3 \log_{10}(M_0) - 6 \tag{8}$$

This equation is also given, and explained, in Fowler (equation 4.21). Check whether your value for the magnitude agrees with that given by the USGS website.