Homework #4: Sea-level rise and mapping toolbox **Due: 5:00 PM 10/03/16**

Please read the following questions carefully and make sure to answer the problems completely. In your MATLAB script(s), please include the problem numbers with your answers. Then use the *Publish* function in MATLAB to publish your script to a *pdf* document. For more on the *Publish* functionality within MATLAB see http://www.mathworks.com/help/matlab/matlab_prog/publishing-matlab-code.html. Upload your *pdf* file to Blackboard under Assignment #4. Your filename should be *GEOS397_HW4_Lastname.pdf*. Hint: You can achieve this automatically by calling your MATLAB script *GEOS397_HW4_Lastname.m*.

Part 1: Make a basemap and determine a crude ocean volume *(30 pts.)*

In order to predict sea-level change we need to know the current state of sea level.

Step 1: Load the topo.mat data set

Use **load** to load the 1x1 deg MATLAB global topography data into memory.

Step 2: Plot a basemap

Use the **axesm** function to plot the topographic raster data with a *Mollweid* projection. Make sure that your figure matches Figure 1 *(5 pts.)*. To do this you will need the following code. In your code, make sure you replace any *% your comment* statements with your own proper comment explaining what each line is doing to the figure.

```
% setup the figure properties that we want
h = figure;
h.InvertHardcopy = 'off'; % (1 pt.) your comment
h.Color = 'k';  % (1 pt.) your comment
h.Position = [100 100 1000 500]; % (1 pt.) your comment
h.PaperPositionMode = 'auto'; % (1 pt.) your comment

% setup the map axes
ax = axesm('Mollweid', 'Frame', 'on', 'Grid', 'on'); % (1 pt.) your comment
setm(ax,'MLabelLocation',60); % (1 pt.) your comment
setm(ax,'PLabelLocation',30); % (1 pt.) your comment
mlabel('MLabelParallel',0);  % (1 pt.) your comment
plabel('PLabelMeridian',-25);  % (1 pt.) your comment
axis('off');  % (1 pt.) your comment
setm(ax,'FontColor',[0.9 0.9 0.9]); % (1 pt.) your comment
setm(ax,'GColor',[0.9 0.9 0.9]);
```

Look back to your practicals to see how to plot the topography and the coastlines. Make sure you that you include a colorbar and set the colorbar font color correctly.

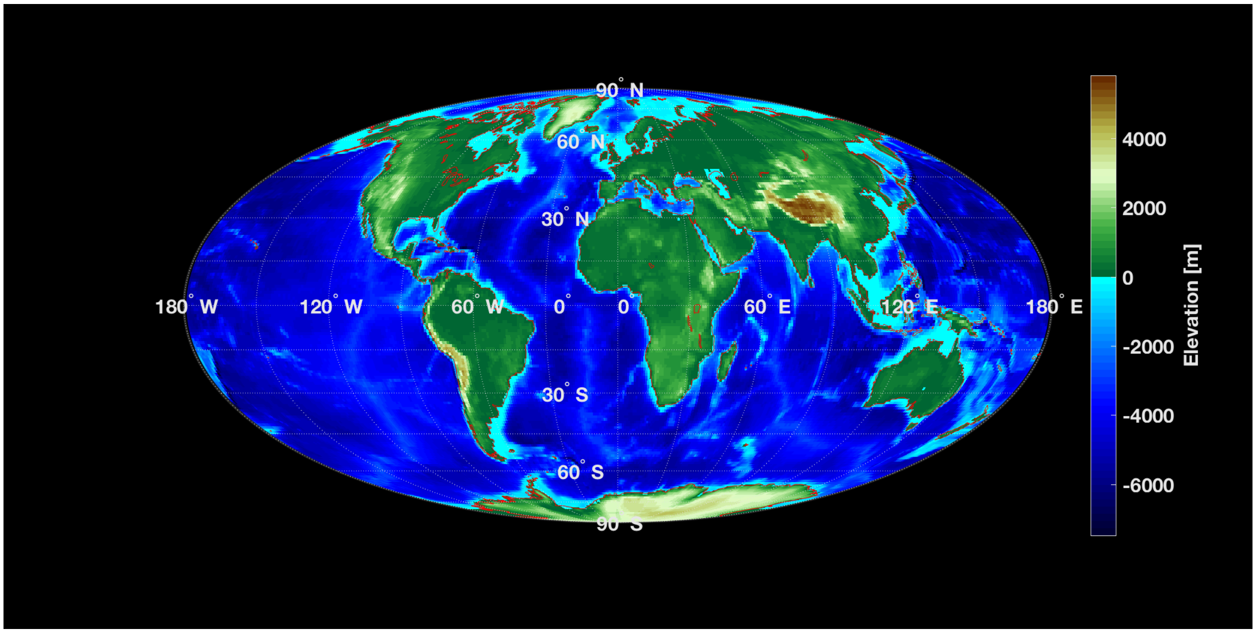

Figure 1: Today's sea level.

Step 3: Modify the *topo* matrix to represent ocean depth

The next step is to convert the ocean depths to kilometers and set the land surface (i.e. pixels above seal-level) to zero elevation so that future computations are simpler *(4 pts.)*. As a check, you should be able to plot something like Figure 2. *(Hint: use logical indexing or an if statement to test if a pixel is above sea level and then set that pixel to zero.)*

Question: How do we compute the volume of the ocean if we only know the depth at each pixel? (2 pts.)

Step 4: Compute the area of each pixel

There are many ways to compute the area of the pixels. Let's first look at a simple approach (which is not completely correct). We know that the *topo* map data is a pixel of 1 deg latitude by 1 degree longitude. Taking the radius of the earth to be 6371 km, compute the area of a square that is 1 deg x 1 deg.

Question: What is the area in km^2 of a 1 deg x 1 deg pixel? (4 pts.)

Question: Using this area, what is the total volume of oceans? (4 pts.)

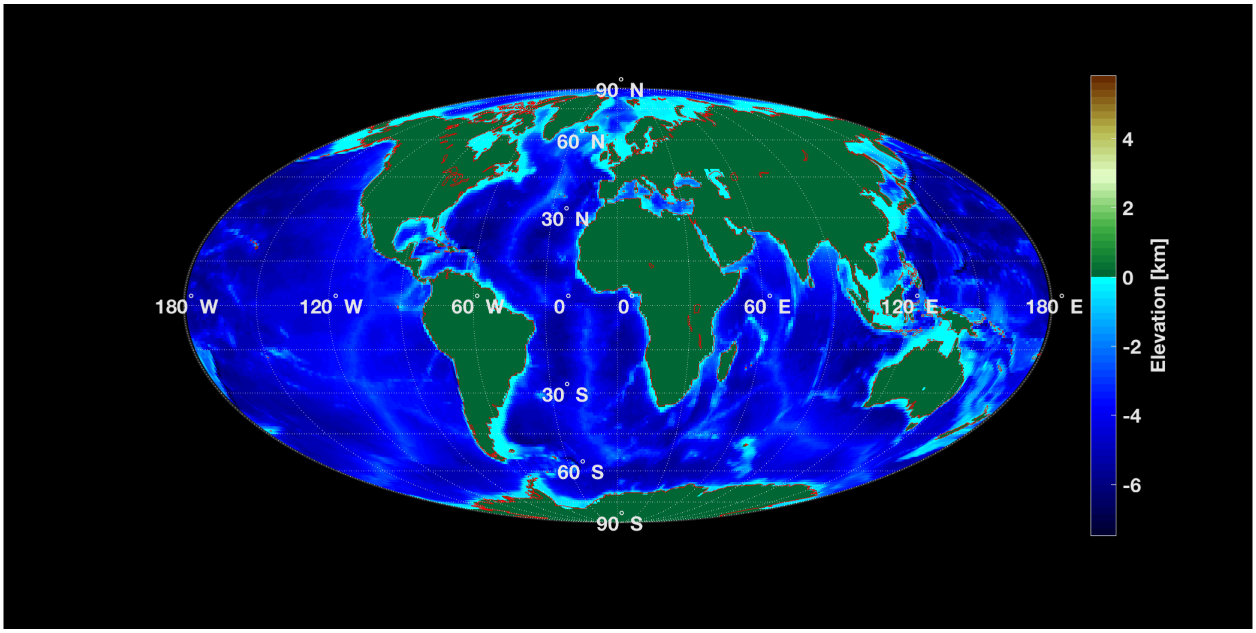

Figure 2: Ocean depth in kilometers.

Part 2: A more accurate volume estimate *(30 pts.)*

If we plot the lines of longitude and latitude on the sphere (Figure 3), we notice that the surface area of each cell bound by 2 lines of latitude and 2 lines of longitude is not constant.

Question: What does that mean in relation to our previous estimate of ocean volume? Are we underestimating or overestimating the true ocean volume? (2 pts.)

Step 1: Compute the area between two lines of latitude

This leads to the question: how best should we compute the ocean volume? Well, we need to simply do a better job of estimating the area of a cell at high latitudes. To do this, we introduce the idea of the spherical cap. We know from previous courses that the surface area of a sphere is $4\pi r^2$. We can compute the area of part of the sphere using the spherical cap area equation

$$A = 2\pi Rh,$$

where $h = R(1 - \sin(lat))$. An example is shown in Figure 4, where latitude is 30N. We can compute the area of the cap at 29N and then subtract the two areas to get only the area around the sphere between 29N-30N (e.g. Figure 4). This approach results in an equation for a the area in a ring around the sphere

$$A_{ring} = 2\pi R^2 |sin(lat1) - sin(lat2)|.$$

Question: Now that we have the area around sphere between two lines of latitude, what is the area of a cell between 29N-30N and two lines of longitude separated by 1 deg? (4 pts.) Hint: think about the fraction of the ring that lines of longitude represent.

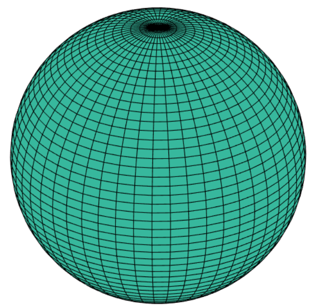

Figure 3: 1 deg x 1 deg grid on the sphere.

Step 2: Compute the area of each pixel

Now that you know how to compute the area of a pixel 1 deg wide in longitude and for any pair of latitudes, compute the area of each pixel on Earth for a 1 deg x 1 deg grid *(14 pts.)*. You should be able to make a plot like those in Figure 5 to check that you have done this correctly.

Step 3: Compute the oceans volume

Now that you have a more accurate estimate of the surface area of each cell, recompute the volume of the oceans.

Question: What is the total volume of the oceans in km^3 *using this new approach? (5 pts.)*

Question: What is the difference in the total volume of the oceans in km^3 *between the two approaches? (5 pts.)*

Figure 4: Left: Area of the spherical cap in yellow (lat = 30N). Yellow is the area we compute with the spherical cap equation. Right: Area on the spherical between lat = 29N and 30N. Yellow is the area we compute when we subtract two spherical cap equations.

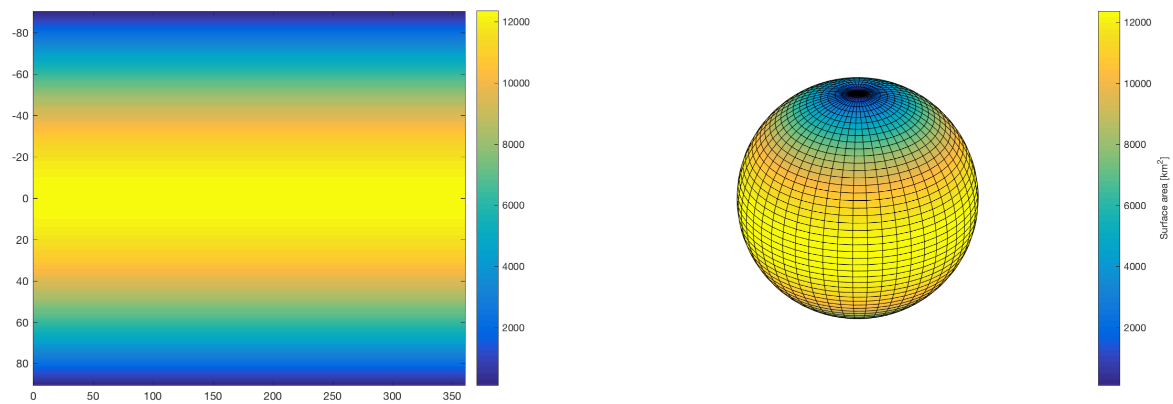

Figure 5: 1 deg x 1 deg areas plotted in matrix form (left) or on the sphere (right).

Part 3: Sea-level rise due to Antarctica *(30 pts.)*

Let's return now the topography map and look at the land area south of latitude 60S. Below this latitude is the continent of Antarctica (Figure 6).

Step 1: Compute the volume of water contained on Antarctica

Using the process that we previously used to compute the volume of oceans, compute the volume of all land mass above sea level that lies of south of 60S.

Question: What is the total volume of mass above sea level? (5 pts.)

We are almost ready to compute sea-level change due to melting Antarctica, but we must first realize that the volume we just computed is for ice, not water. To convert volume of ice to volume of water, multiply

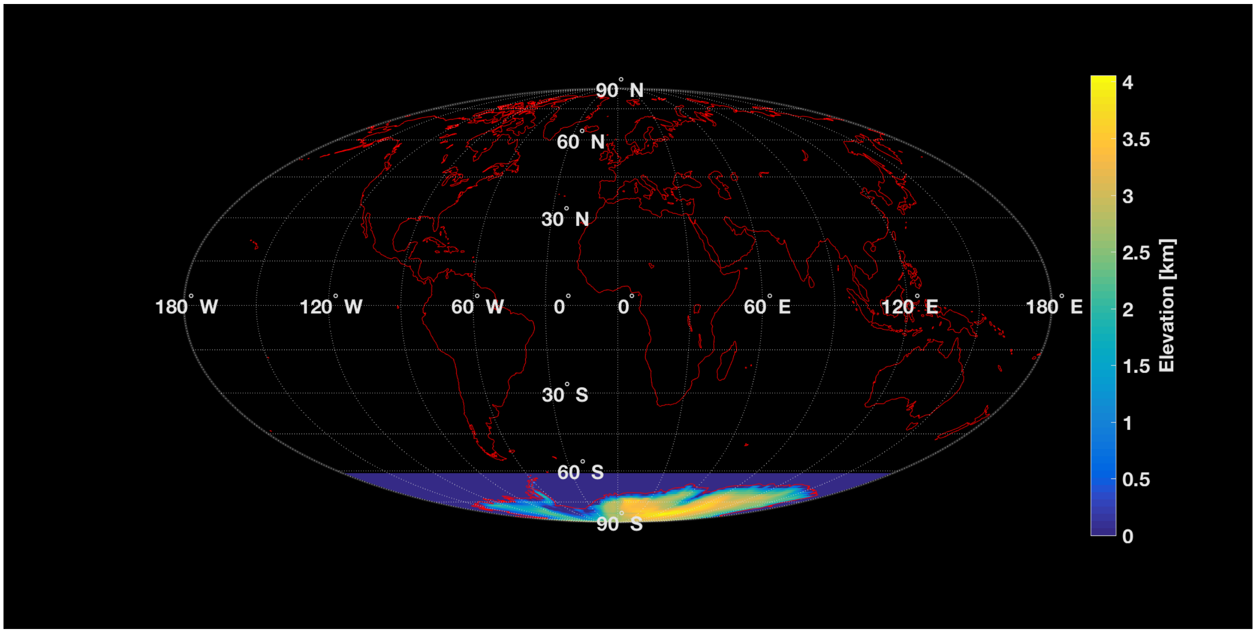

Figure 6: Topography of Antarctica.

your previous estimate of volume above sea level by 0.9.

Question: What is the total volume of liquid water stored in ice in Antarctica? (5 pts.)

Step 2: Compute the change in total ocean volume for incremental changes in sea-level height

We are now going to figure out just how high sea level would rise if we added the water volume contained on Antarctica. But rather that add this volume to current volume and then estimate sea-level change, we are going to go the other way. We are going to add 1 m of water to the globe, compute the total volume and compare with the current volume plus that of Antarctica. When those two volumes are equal, we have found the expected sea-level rise by melting the ice on Antarctica.

Return now to your *topo* matrix. Subtract 1 m of elevation to this map and recompute the total ocean volume. Repeat this procedure up two 100 m at a 1 m interval. You should have a vector of sea-level increases and one of total volume *(5 pts.)*. When I compute this, I get the relationship shown in Figure 7.

Step 3: Match the change in volume with the volume held on Antarctica

Now that you have an estimate of ocean volume change with sea-level rise, determine which sea-level rise value matches the volume of water held on Antarctica *(5 pts.)*. This is the expected rise in sea level if we melted Antarctica.

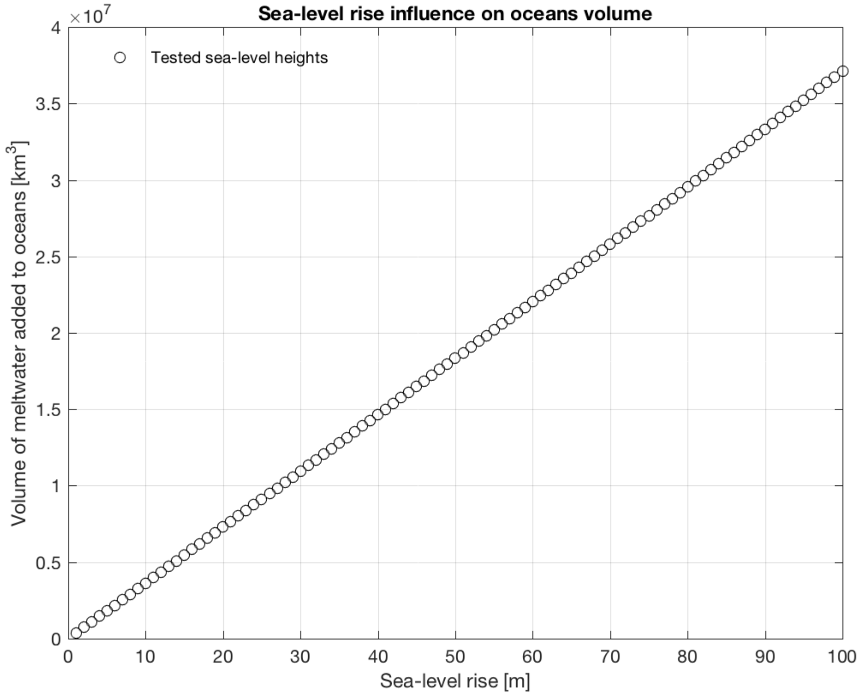

Figure 7: Modeled change in total ocean volume for 1 m increases in sea level.

Step 4: Plot the new coastline

Return now to your map of the Earth and the current coastline. Using **contourm** to plot another contour at the sea-level rise you determined in the last section *(5 pts.)*.

Question: List two places in the world that would be inundated with water if all of the ice Antarctica melted. (2 pts.)

Question: List all possible things in this modeling approach that could be improved or made more accurate. What are we neglecting? (3 pts.)

Part 4: Sea-level rise due to Greenland *(10 pts.)*

Explain how you would include the ice stored on Greenland in your sea-level rise modeling. *(5 pts.)*

Question: What is the liquid water volume stored on Greenland in ice form? (5 pts.)