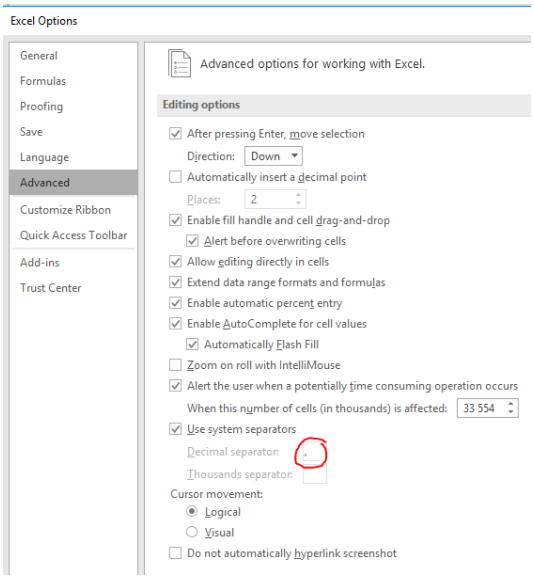
Windows users: Before starting the assignment, change the decimal separator from comma to point in the options of excel (File-Options-Advanced)



Mac users: Before starting the assignment, change the decimal separator of the system from comma to point: Click on the Apple button, Select System Preferences, Select Text and Language, Click on Formats, Under Numbers select Customize, Change the Decimal separator from a comma (,) to a full stop (.), Then click on Ok/Save.

Introductory task:

Consider the x axis, and two points (nodes) on the axis with values “A” and “B”, marking the start and end of a line (here B>A). If you want to split the line in “N” identical sections, the length of each section (Δx) is given by:

$$\Delta x = (B-A)/N$$

And there will a total of N+1 nodes. There are two nodes defining each section, start node and end node. For example, for the first section the start node is located at A, and the end node is located at A+ Δx. For the second section the start node is located at A+ Δx, and the end node at A+ 2*Δx, and so forth…

- Make a hand sketch of a system where A=0, B = 10 and N=3. Number the sections and nodes.
- Create an excel sheet where the user provides: the value of the start and end node and the desired number of nodes (for example in cells B1, B2, B3, respectively). To make your excel sheet nicer, Put in Cells A1, A2 and A3 text identifying the input. Using these values estimate the values of the nodes. You can do this in column B, from row 6, and use column A to provide the name of the node.
    - **Tip1:** pre calculate the value of Δx beforehand (for example in Cell B4).
    - **Tip2:** Note that you can calculate the value of a node with a formula (after typing the symbol “=”) equal to the value of the previous node (Cell) plus Δx.

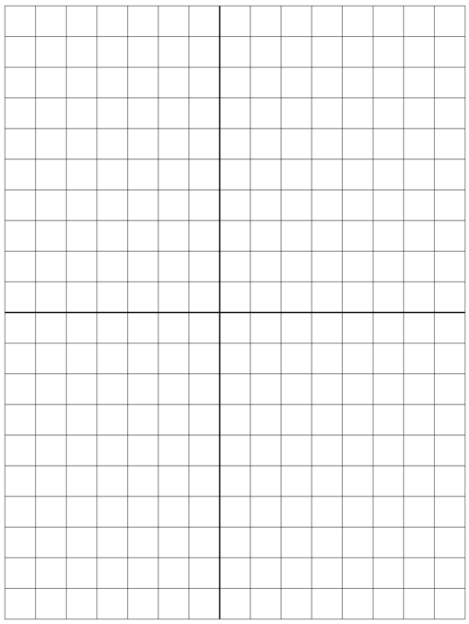
  - **Tip3:** when you "drag down" a cell that has a formula, excel will try to move the input cell one location down also. To avoid this, you can include two dollar signs before and after the letter of the cell, e.g. "A1", or by pressing F4 when the cursor is in the cell.
- Will the formula still work if A>B?, Discuss in your group.
- It is also possible to create sections with a variable value for Δx. This is useful for example when one wishes to have more nodes in the center or closer to the start or closer to the end.

TASK 1 - creating a grid in excel

Using the technique presented in introductory task, create a rectangular grid (with X as latitude and Y as longitude) for your area of interest where the pipeline will be placed. The extreme points delimiting the area are the coordinates of the start-point (a,b) and end-point of the pipeline (c,d). You decide on the number of nodes for each coordinate, but it should be at least 10.

Suggestions and considerations

- More points will provide better resolution of the area, but it will require more work to gather the information later.
- Use at least 4 decimal points for the values of X and Y.
- It could happen that the pipeline might fall outside of the rectangular area of interest. For this reason, It is recommended to add an extra node to both ends of X and Y, just in case.

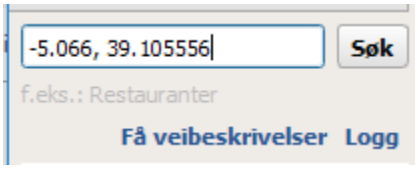


You can create this grid in an excel file, in the following manner (an example is shown below with 10X10 points grid):

	A	B	C	D	E	F	G	H	I	J	K
1		**Y1**	**Y2**	**Y3**	**Y4**	**Y5**	**Y6**	**Y7**	**Y8**	**Y9**	**Y10**
2	**X1**										
3	**X2**										
4	**X3**										
5	**X4**										
6	**X5**										
7	**X6**										
8	**X7**										
9	**X8**										
10	**X9**										
11	**X10**										

TASK 2 - finding elevation (based on coordinates)

You have now to retrieve the elevation/depth of all points on the grid (each combination of X and Y). This must be done manually by using google earth pro (https://www.google.com/earth/). You will have to download the software and install it on your computer. **TIP:** Collaborate with other teams to split the points and do this task faster!



TASK 3 - elevation/depth color map.

For making the color map of the elevation/depth, we will use the program GnuPlot[1] (look at the zip file provided). For mac users, you have to follow the procedure[2].

Extract the zip file provided in your computer. In the folder gnuplot\bin\ are the files:

- "elevation.dat": you should substitute in this file the elevation/depth data you found. However, the format is slightly different. You will have to rearrange the data in the following manner:

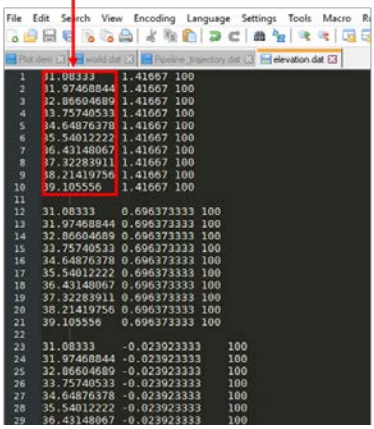
[1] http://www.gnuplot.info/

[2]

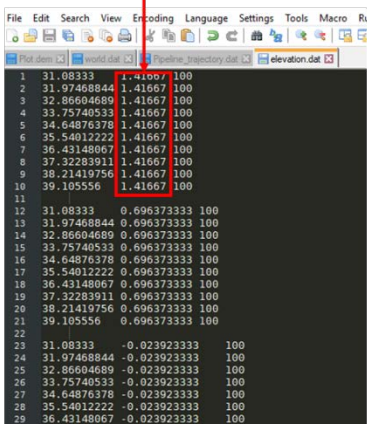
1. Press `Command+Space` and type ***Terminal*** and press ***enter/return*** key.
2. Run in Terminal app:
   `ruby -e "$(curl -fsSL https://raw.githubusercontent.com/Homebrew/install/master/install)" < /dev/null 2> /dev/null`
   and press ***enter/return*** key.
   If the screen prompts you to enter a password, please enter your Mac's user password to continue. When you type the password, it won't be displayed on screen, but the system would accept it. So just type your password and press ENTER/RETURN key. Then wait for the command to finish.
3. Run:
   `brew install gnuplot`

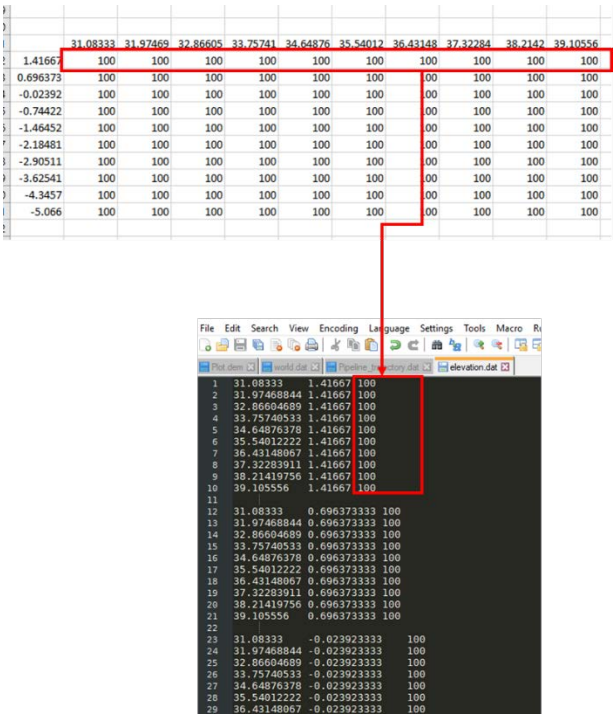
Done! You can now use `gnuplot`.

	31.08333	31.97469	32.86605	33.75741	34.64876	35.54012	36.43148	37.32284	38.2142	39.10556
1.41667	100	100	100	100	100	100	100	100	100	100
0.696373	100	100	100	100	100	100	100	100	100	100
-0.02392	100	100	100	100	100	100	100	100	100	100
-0.74422	100	100	100	100	100	100	100	100	100	100
-1.46452	100	100	100	100	100	100	100	100	100	100
-2.18481	100	100	100	100	100	100	100	100	100	100
-2.90511	100	100	100	100	100	100	100	100	100	100
-3.62541	100	100	100	100	100	100	100	100	100	100
-4.3457	100	100	100	100	100	100	100	100	100	100
-5.066	100	100	100	100	100	100	100	100	100	100



	31.08333	31.97469	32.86605	33.75741	34.64876	35.54012	36.43148	37.32284	38.2142	39.10556
1.41667	100	100	100	100	100	100	100	100	100	100
0.696373	100	100	100	100	100	100	100	100	100	100
-0.02392	100	100	100	100	100	100	100	100	100	100
-0.74422	100	100	100	100	100	100	100	100	100	100
-1.46452	100	100	100	100	100	100	100	100	100	100
-2.18481	100	100	100	100	100	100	100	100	100	100
-2.90511	100	100	100	100	100	100	100	100	100	100
-3.62541	100	100	100	100	100	100	100	100	100	100
-4.3457	100	100	100	100	100	100	100	100	100	100
-5.066	100	100	100	100	100	100	100	100	100	100



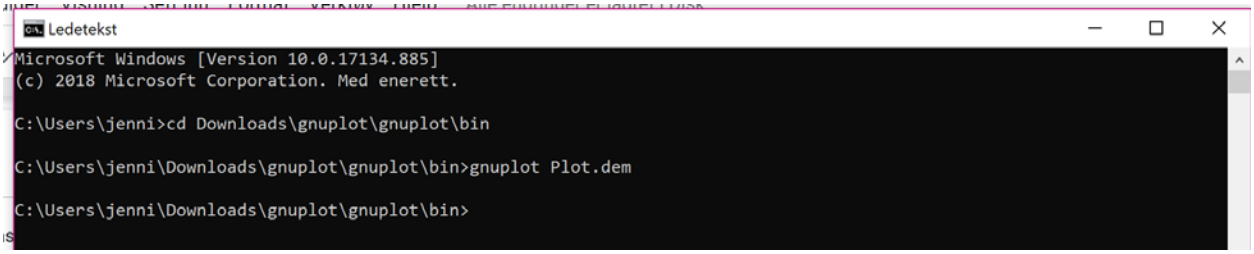


And repeat for the next row. **REMEMBER THE SPACE IN BETWEEN!**

Tip. In Excel, if you want to change the orientation of a set of numbers, you can copy them and then use the option “paste especial” ticking on the options “values” and “transpose”.

- “Plot.dem” this is the main file that has the setting of the plot. Modify the range of latitude and longitude and the minimum and maximum elevation/depth according to the ranges of your table (lines 2,7,8).

To generate the plot, Open the command prompt (run cmd in Windows, or terminal in mac), navigate to the folder gnuplot\bin\. Once there, type “gnuplot.exe Plot.dem” (or simply “gnuplot Plot.dem” in mac) . The script should generate a file Map.png in the gnuplot\bin\ folder.



TIP: You can use this map not only to plot elevation but for example if there is a natural part on coordinate. For example, by using a big negative number where there is a natural park, the coordinate will be plotted in black color.

TASK 4 - creating the trajectory of the pipeline.

Use google Earth Pro to define a pipeline trajectory ("legg til sti",  on the upper toolbar) between the start-point and end-point. Use at least 10 points to define your trajectory. Once you are done, on the left side menu, right click on the path and select "Lagre sted som…" and save the file as .kml. Open this file with a text editor (such as notepad) and copy the line below "<coordinates>". This line contains the longitude and latitude (IN THAT ORDER) of all points you have defined in your pipe. Neglect the third coordinate.

In excel, in a different sheet, create a table (like the one shown below) to fill the coordinates (on columns B,C, E,F) for each pipe section. As you have used 10 points to define the pipeline trajectory, there will be 9 pipe sections.

	A	B	C	D	E	F	G	H	I
1	**PIPELINE: OPTION 1**								
2	**SECTION**	**X-START**	**Y-START**	**Elevation-START**	**X-END**	**Y-END**	**Elevation-END**	**Pipe LENGTH**	**Pipe LENGTH**
3				**[m]**			**[m]**	**[m]**	**[km]**
4	1								
5	2								
6	3								
7	4								
8	5								
9	6								
10	7								
11	8								
12	9								
13								**TOTAL=**	

Learning task: Create a custom VBA function

- While in excel, press alt+F11. This will open the VBA programming interface. On the tree on the left, right click on the folder "Microsoft Excel Objects" and select "add module". Write the following:

```
Function sumi (a,b)
    sumi=a+b
End Function
```

- Press alt+F11 to return to Excel.
- To use the function, while on a cell: 1. type the name of the function and open parenthesis OR 2. press the "fx" symbol and look for the function under "user defined". If you are using the first option, remember to separate the arguments of the function with ";".
- When saving the excel sheet, remember to save it as a "macro enabled excel sheet", file extension .xlsm. **Otherwise, your VBA function will be lost**

TASK 5 - calculation of the elevation/ depth of each pipeline coordinate

To calculate the elevation/depth of each coordinate of the pipeline, we will perform a bi-linear interpolation on the points gathered in Step 1. You can read more about this interpolation in the Wikipedia[3] website. You will use an excel function pre-made for you. Add it in the VBA module following the steps described in step 8.

The first argument is the latitude. The second argument the longitude. The third argument is the elevation table created in step 1 (you select the whole table, including the X and Y values. Remember to Freeze the table with "F4"). The fourth argument is 1 if X values are in ascending order and 0 if X values are in descending order. The fifth argument is 1 if Y values are in ascending order and 0 if Y values are in descending order.

Voilá, this gives you the elevation at any particular latitude and longitude.

Learning task: Latitude and longitude. Read the following information[4]

[3] https://en.wikipedia.org/wiki/Bilinear_interpolation

[4] Taken from: https://www.mkompf.com/gps/distcalc.html

As you can see, the meridians and parallels are straight lines which are parallel and perpendicular respectively to each other. We can therefore view the Earth's surface as a plane and use for this relatively small area the **Pythagorean Theorem** ↗ for distance calculation:

```
distance = sqrt(dx * dx + dy * dy)

with distance: Distance in kilometer (km)
dx = 71.5 * (lon1 - lon2)
dy = 111.3 * (lat1 - lat2)
lat1, lat2, lon1, lon2: Latitude, Longitude in degrees
```

When specifying the length and width in degrees, there is the distance in kilometers. The constant 111.3 is the distance between two circles of latitude in km and 71.5 is the average distance between two meridians in our latitudes.

Improved method

While the distance between two circles of latitude is always constant 111.3 km, the distance between two meridians varies depending on the latitude: At the equator, it is also 111.3 km, but at the poles, however 0. More precisely, their distance is calculated by the formula

```
111.3 * cos(lat)
```

This can be incorporated into the calculation formula. The value of lat is chosen from the average of lat1 and lat2.

In the calculation using a computer it is important to remember that although most programming languages provide the cosine function, it is usually expecting the angle in radians - not in degrees! The conversion from degrees to radians is done according to the relation:

```
1° = π/180 rad ≈ 0.01745
```

The full, improved formula for the distance calculation is then:

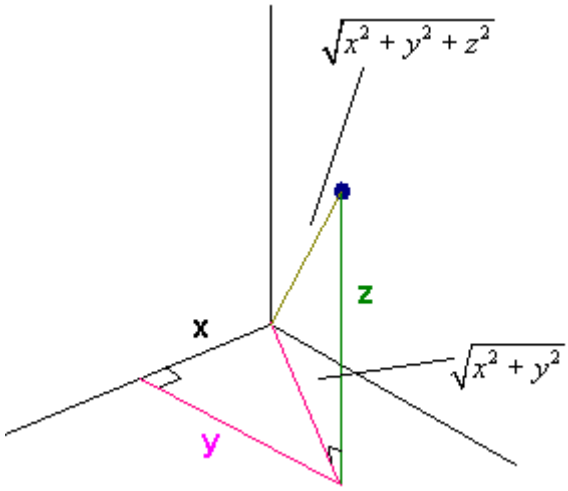
```
distance = sqrt(dx * dx + dy * dy)

with distance: Distance in km
dx = 111.3 * cos(lat) * (lon1 - lon2)
lat = (lat1 + lat2) / 2 * 0.01745
dy = 111.3 * (lat1 - lat2)
lat1, lat2, lon1, lon2: Latitude, Longitude in degrees
```

- Estimate the distance between the start and end point of the pipe using the “Improved method” indicated above.

TASK 6

Estimate the length of each pipeline segment can be estimated by geometry using the expression explained in the previous, however remember to include the elevation/depth change[5]!

[5] Taken from https://ltcconline.net/greenl/courses/117/DerivNvar/threeDCoords.htm



TASK 7

Plot the pipeline trajectory in the elevation/depth map. For this you will have to modify the file "Pipeline_trajectory.dat" in the folder gnuplot\bin\ . Substitute in this file the coordinates of your pipeline. (put longitude first and then latitude). Then Remove the "#" in lines 19 and 20 of the Plot.dem file.

TASK 8

Make a plot in excel of elevation/depth vs. distance along the pipeline.

DELIVERABLES

Prepare a powerpoint presentation to present in front of the company with the following:

- A short description of the problem
- A short description of the tasks performed.
- A short description of the area, the elevation map, and describing special considerations.
- The pipeline trajectories analyzed
- The final trajectory, cost, pressure drop, length (in km) and the justification of why it was selected.