Modelling volcanic plumes – Exercises

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Date:

Exercise 1 – Raffling a duck (Archimedes' law)

A rubber duck floats gently in a tank of fresh water at room temperature. Could you guess its total weight just looking at it? Pay attention that the duck has in its interior an unknown number of 1.5V batteries. Be careful of writing all the logical steps that allows you guessing the weight.

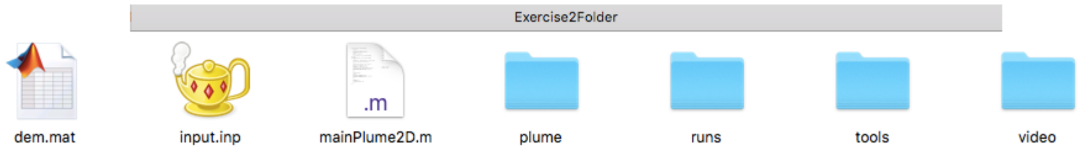
(Maybe) useful quantities for the problem are: rubber density (1522 $\frac{kg}{m^3}$*), fresh water density (998* $\frac{kg}{m^3}$*), 1.5V battery weight (0.012* kg*).*

[*Write here your solution*]

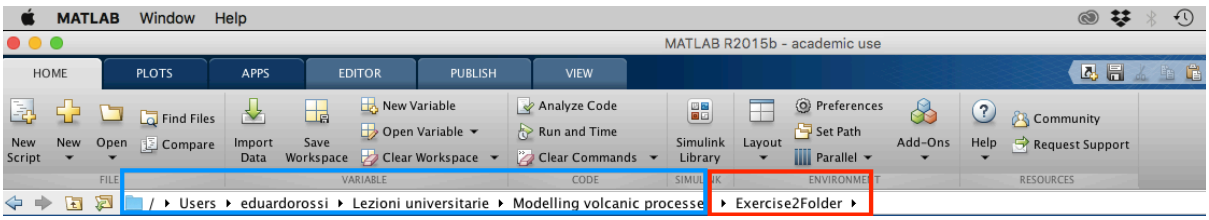
Exercise 2 – Plume modelling using Matlab

Introduction

In this exercise you are going to use the Degruyter&Bonadonna (2012) plume model to test the plume rise in different conditions. The main folder where you have to work is "**Exercise2Folder**", where the following files are present.



In order for Matlab to work fine you should set the path properly. Referring to the figure below, please be sure that the path ends with "*Exercise2Folder*", which means you are in the right folder where all the codes are. The blue part will be different from the screenshot, but the red one should be the same.



How is the code structured? The most important file that you have to modify is the "**input.inp**" file, that you can open with "windows notebook". If you open "*input.inp*" you notice several lines where you can modify the input source parameters and the meteorological settings.

```
% Atmospheric conditions
    11000    % Tropopause height [m]
    20000    % Stratopause height [m]
    288      % Atmospheric temperature at the vent [K]
    -6.5     % Temperature gradient troposphere per 1000 m [K]
    2        % Temperature gradient stratosphere per 1000 m [K]
    0.1      % Radial entrainment
    0.5      % Wind entrainment
    0.9      % Relative humidity [%]
    90       % Azimuth wind angle
    101325   % Atmospheric pressure at sea level [Pa]
    0        % Atmosphere division profile starting (=0): [m]
    20000    % Maximum cautelative height atmosphere (= higher than plume): [m]
    2000     % Number of points to divide the entire vertical atmosphere:
    18.32e-6     % Air dyn. visc. [Pa s]->[kg/(m s)] {Also used by aggregation}
    5.43e-4 % Water dyn. visc.: [Pa s]-> [kg/(m s)] {Also used by aggregation}
    1.22     % Air density at sea-level: [kg/m^3]
    0.01     % Brunt vaisala frequency of the troposphere: [1/s]
    0.02     % Brunt vaisala frequency of the stratosphere: [1/s]
% Eruption initial conditions
    3200     % Vent height a.s.l [m]
    250      % Plume velocity [m/s]
    1182     % Plume temperature [K]
    0.95     % Mass fraction solid phase
    0        % Mass fraction liquid phase
    0.05     % Mass fraction dry air phase (water vapor is the complementary to 1 of the sum of all the phases)
    46.20    % Vent latitude
    -122.18 % Vent longitude
    700      % Diffusivity in the plume (for sedimentation)
    1000     % Density of liquid water in the plume [kg/m^3]
    2350     % Density of solid particles in the plume [kg/m^3]
    1e7      % Mass flow rate at the vent [Kg/s]
    100      % Plume radius: 0 = dir. MFR; otherwise indir. MFR
    0.0098   % 0 no condensation., 1/(2.8*3600)=9.9206e-005 moderate, 1/(1.7*60)=0.0098
    1E+8     % Total mass erupted [kg]
% Working folder and meteo profiles
    Exercise1    % Name of the folder for the single run
    windprofile      % Name of the wind profile: IT MUST BE IN THE FORMAT [km , m/s]!!!
    temperatureprofile      % Name of the temp profile: IT MUST BE IN THE FORMAT [km , C]!!!
    txt      % Extention of files in the "runs" folder
% Sedimentation variables and single run folder
    0        % Model: strong [0]; weak [1]
    1        % Evaluation: base [0]; ground [1]; both [2]
    0.5      % Eccentricity of the elipse for sedimentation
    0.8      % Shape factor for a gravitationally spreading plume (LAMBDA in the paper)
    100      % N points to divide the atmosphere within the basecurrent
    0        % Sedimentation map: no [0]; yes [1]
% Thermodynamic parameters and physical constant
    998      % Specific heat capacity: dry air
    1952     % Specific heat capacity: water vapour
    4190     % Specific heat capacity: liquid water
    1250     % Specific heat capacity: solid fraction
    2.26e6   % Latent heat vaporization
```

Let’s have a look closely. Two main important parts of “*input.inp*” are the following ones, where you can control the initial plume source parameters…

```
% Atmospheric conditions
    11000   % Tropopause height [m]
    20000   % Stratopause height [m]
    288     % Atmospheric temperature at the vent [K]
    -6.5    % Temperature gradient troposphere per 1000 m [K]
    2       % Temperature gradient stratosphere per 1000 m [K]
    0.1     % Radial entrainment
    0.5     % Wind entrainment
    0.9     % Relative humidity [%]
    90      % Azimuth wind angle
    101325  % Atmospheric pressure at sea level [Pa]
    0       % Atmosphere division profile starting (=0): [m]
    20000   % Maximum cautelative height atmosphere (= higher than plume): [m]
    2000    % Number of points to divide the entire vertical atmosphere:
    18.32e-6    % Air dyn. visc. [Pa s]->[kg/(m s)] {Also used by aggregation}
    5.43e-4 % Water dyn. visc.: [Pa s]-> [kg/(m s)] {Also used by aggregation}
    1.22    % Air density at sea-level: [kg/m^3]
    0.01    % Brunt vaisala frequency of the troposphere: [1/s]
    0.02    % Brunt vaisala frequency of the stratosphere: [1/s]
% Eruption initial conditions
    3200    % Vent height a.s.l [m]
    250     % Plume velocity [m/s]
    1182    % Plume temperature [K]
    0.95    % Mass fraction solid phase
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    46.20   % Vent latitude
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    700     % Diffusivity in the plume (for sedimentation)
    1000    % Density of liquid water in the plume [kg/m^3]
    2350    % Density of solid particles in the plume [kg/m^3]
    1e7     % Mass flow rate at the vent [Kg/s]
    100     % Plume radius: 0 = dir. MFR; otherwise indir. MFR
    0.0098  % 0 no condensation., 1/(2.8*3600)=9.9206e-005 moderate, 1/(1.7*60)=0.0098
    1E+8    % Total mass erupted [kg]
% Working folder and meteo profiles
    Exercise1   % Name of the folder for the single run
    windprofile     % Name of the wind profile: IT MUST BE IN THE FORMAT [km , m/s]!!!
    temperatureprofile      % Name of the temp profile: IT MUST BE IN THE FORMAT [km , C]!!!
    txt     % Extention of files in the "runs" folder
% Sedimentation variables and single run folder
    0       % Model: strong [0]; weak [1]
    1       % Evaluation: base [0]; ground [1]; both [2]
    0.5     % Eccentricity of the elipse for sedimentation
    0.8     % Shape factor for a gravitationally spreading plume (LAMBDA in the paper)
    100     % N points to divide the atmosphere within the basecurrent
    0       % Sedimentation map: no [0]; yes [1]
% Thermodynamic parameters and physical constant
    998     % Specific heat capacity: dry air
    1952    % Specific heat capacity: water vapour
    4190    % Specific heat capacity: liquid water
    1250    % Specific heat capacity: solid fraction
    2.26e6  % Latent heat vaporization
```

PLUME SOURCE PARAMETERS

… and the atmospheric conditions.

```
% Atmospheric conditions
    11000   % Tropopause height [m]
    20000   % Stratopause height [m]
    288     % Atmospheric temperature at the vent [K]
    -6.5    % Temperature gradient troposphere per 1000 m [K]
    2       % Temperature gradient stratosphere per 1000 m [K]
    0.1     % Radial entrainment
    0.5     % Wind entrainment
    0.9     % Relative humidity [%]
    90      % Azimuth wind angle
    101325  % Atmospheric pressure at sea level [Pa]
    0       % Atmosphere division profile starting (=0): [m]
    20000   % Maximum cautelative height atmosphere (= higher than plume): [m]
    2000    % Number of points to divide the entire vertical atmosphere:
    18.32e-6    % Air dyn. visc. [Pa s]->[kg/(m s)] {Also used by aggregation}
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    1e7     % Mass flow rate at the vent [Kg/s]
    100     % Plume radius: 0 = dir. MFR; otherwise indir. MFR
    0.0098  % 0 no condensation., 1/(2.8*3600)=9.9206e-005 moderate, 1/(1.7*60)=0.0098
    1E+8    % Total mass erupted [kg]
% Working folder and meteo profiles
    Exercise1   % Name of the folder for the single run
    windprofile     % Name of the wind profile: IT MUST BE IN THE FORMAT [km , m/s]!!!
    temperatureprofile      % Name of the temp profile: IT MUST BE IN THE FORMAT [km , C]!!!
    txt     % Extention of files in the "runs" folder
% Sedimentation variables and single run folder
    0       % Model: strong [0]; weak [1]
    1       % Evaluation: base [0]; ground [1]; both [2]
    0.5     % Eccentricity of the elipse for sedimentation
    0.8     % Shape factor for a gravitationally spreading plume (LAMBDA in the paper)
    100     % N points to divide the atmosphere within the basecurrent
    0       % Sedimentation map: no [0]; yes [1]
% Thermodynamic parameters and physical constant
    998     % Specific heat capacity: dry air
    1952    % Specific heat capacity: water vapour
    4190    % Specific heat capacity: liquid water
    1250    % Specific heat capacity: solid fraction
    2.26e6  % Latent heat vaporization
```
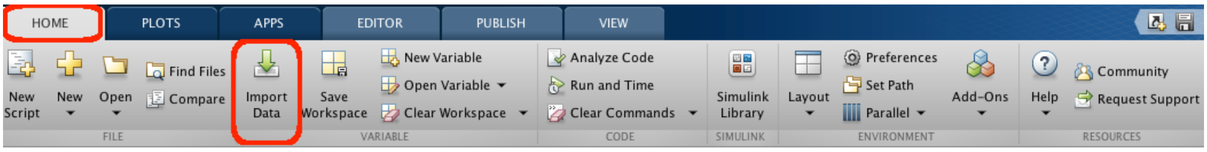

WIND and TEMPERATURE PROFILE

<u>BE CAREFUL TO SAVE THE FILE “INPUT.INP” EACH TIME YOU MODIFY IT!!!!</u>

Please notice that in the plume source parameters the mass fraction of water vapor is calculated as the complementary to 1 of the mass fractions of solid particles, dry air and liquid water (i.e. $n_v = 1 - n_d - n_s - n_l$).
In the following you will have to use different profiles, both for wind and temperature. These files are already present in the "*runs*" folder. Each exercise has its own folder: during the exercise you will have simply to type the name of the folder in which the exercise is contained. For example, in the screenshot above "*Exercise1*" is the name of folder that contains the two atmospheric profiles "*windprofile.txt*" and "*temperatureprofile.txt*". All the exercises are contained in the folder "**runs**".

Before starting the exercise you need to import the DEM for the plume. Go to « Import Data » under « Home ».



Select « dem.mat » and import the file. If everything is fine you should see the name "dem" in your Matlab workspace.
To run the code type "***mainPlume2D(dem);***" in the command window. The code generates some information in the command window and 7 figures.

Exercise 2.1

In this exercise you will run your first simulation with the code. Pay attention to the parameters with a red arrow and set them as in the following screenshot.

```
% Eruption initial conditions
    3200     % Vent height a.s.l [m]
    250      % Plume velocity [m/s]
    1400     % Plume temperature [K]
    0.97     % Mass fraction solid phase
    0        % Mass fraction liquid phase
    0.03     % Mass fraction dry air phase (water vapor is the complementary to 1 of the sum of all the phases)
    46.20    % Vent latitude
    -122.18  % Vent longitude
    700      % Diffusivity in the plume (for sedimentation)
    1000     % Density of liquid water in the plume [kg/m^3]
    2350     % Density of solid particles in the plume [kg/m^3]
    1e8      % Mass Eruption Rate at the vent [Kg/s]
    50       % Plume radius: 0 = dir. MER; otherwise indir. MER
    0.0098   % 0 no condensation., 1/(2.8*3600)=9.9206e-005 moderate, 1/(1.7*60)=0.0098
    1E+8     % Total mass erupted [kg]
% Working folder and meteo profiles
    Exercise2p1 % Name of the folder for the single run
    windprofile      % Name of the wind profile: IT MUST BE IN THE FORMAT [km , m/s]!!!
    temperatureprofile      % Name of the temp profile: IT MUST BE IN THE FORMAT [km , C]!!!
    txt      % Extention of files in the "runs" folder
```

Where we set …
Plume initial exit velocity: 250 m/s
Plume initial radius: 50 m
Plume initial temperature: 1400 K
Mass fraction of solid phase: 0.97
Mass fraction of liquid phase: 0
Mass fraction of dry air: 0.03

Question 1: concerning the mass fractions of different phases (e.g. solid, dry, liquid, vapor). What is their sum? Why? Do you think this sum changes during the plume rise? Do you think that the mass fractions are constant across the plume? In case of an eruption occurring at a location characterized by a humid atmosphere, which one of the mass fraction would be more affected?

Type "mainPlume2D(dem);" in the "Command window" to run the simulation.

Question 2: by looking at Figure 1 in Matlab, what can you immediately say if I ask you "Is the plume weak or strong"?

Question 3: pay attention to Figure 2 in Matlab. How many NBL do you see? What is their height? What are the leading physical phenomena governing the regions below, within and above the NBLs?

Question 4: pay attention to Figure 3 in Matlab. At what height the plume temperature drops below 0°C? How do you think the entrainment affects this plot?

Question 5: have a look to Figure 4 in Matlab, does the figure confirm your answer to Question 1?

Question 6 (***optional***): looking at Figure 1 in Matlab, can you roughly say if there is a height in which the plume is not accelerating? If you compare this region with Figure 2 in Matlab, what do you observe? Is it true that the velocity of the plume decreases even if there is a positive buoyancy? Why?

Exercise 2.2

Start the simulation with the following setup.

```
% Eruption initial conditions
    3200    % Vent height a.s.l [m]
    10      % Plume velocity [m/s]
    1182    % Plume temperature [K]
    0.95    % Mass fraction solid phase
    0       % Mass fraction liquid phase
    0.05    % Mass fraction dry air phase (water vapor is the complementary to 1 of the sum of all the phases)
    46.20   % Vent latitude
    -122.18 % Vent longitude
    700     % Diffusivity in the plume (for sedimentation)
    1000    % Density of liquid water in the plume [kg/m^3]
    2350    % Density of solid particles in the plume [kg/m^3]
    1e7     % Mass flow rate at the vent [Kg/s]
    50      % Plume radius: 0 = dir. MER; otherwise indir. MER
    0.0098  % 0 no condensation., 1/(2.8*3600)=9.9206e-005 moderate, 1/(1.7*60)=0.0098
    1E+8    % Total mass erupted [kg]
% Working folder and meteo profiles
    Exercise2p2 % Name of the folder for the single run
    windprofile     % Name of the wind profile: IT MUST BE IN THE FORMAT [km , m/s]!!!
    temperatureprofile      % Name of the temp profile: IT MUST BE IN THE FORMAT [km , C]!!!
    txt     % Extention of files in the "runs" folder
```

Where the red arrows underline the following initial conditions:

Plume initial exit velocity: 10 m/s
Plume initial radius: 50 m
Plume initial temperature: 1182 K
Mass fraction of solid phase: 0.95
Mass fraction of liquid phase: 0
Mass fraction of dry air: 0.05
Name of the folder for the single run: "*Exercise2p2*"

Run the simulation typing "*mainPlume2D(dem);*" in the "Command window".

Question 7: what is the height of the erupted column? Is the plume collapsed or buoyant?

Question 8: which one of the above initial parameters should be increased to make the plume buoyant? Why?

Question 9: looking at the figures produced from the code, can you answer to the following question "Is the plume strong or weak"? Why?

Exercise 2.3

Start the simulation with the following setup.

```
% Eruption initial conditions
    3200    % Vent height a.s.l [m]
    100     % Plume velocity [m/s]
    1182    % Plume temperature [K]
    0.95    % Mass fraction solid phase
    0       % Mass fraction liquid phase
    0.05    % Mass fraction dry air phase (water vapor is the complementary to 1 of the sum of all the phases)
    46.20   % Vent latitude
    -122.18 % Vent longitude
    700     % Diffusivity in the plume (for sedimentation)
    1000    % Density of liquid water in the plume [kg/m^3]
    2350    % Density of solid particles in the plume [kg/m^3]
    1e7     % Mass flow rate at the vent [Kg/s]
    50      % Plume radius: 0 = dir. MER; otherwise indir. MER
    0.0098  % 0 no condensation., 1/(2.8*3600)=9.9206e-005 moderate, 1/(1.7*60)=0.0098
    1E+8    % Total mass erupted [kg]
% Working folder and meteo profiles
    Exercise2p3 % Name of the folder for the single run
    windprofile     % Name of the wind profile: IT MUST BE IN THE FORMAT [km , m/s]!!!
    temperatureprofile     % Name of the temp profile: IT MUST BE IN THE FORMAT [km , C]!!!
    txt     % Extention of files in the "runs" folder
```

Where the red arrows underline the following initial conditions:

Plume initial exit velocity: 100 m/s
Plume initial radius: 50 m
Plume initial temperature: 1182 K
Mass fraction of solid phase: 0.95
Mass fraction of liquid phase: 0
Mass fraction of dry air: 0.05

Question 10: what is the height of the erupted column? Is the plume collapsed or buoyant?

Question 11: Do you think the plume can be classified as weak or strong? Why?

Exercise 2.4

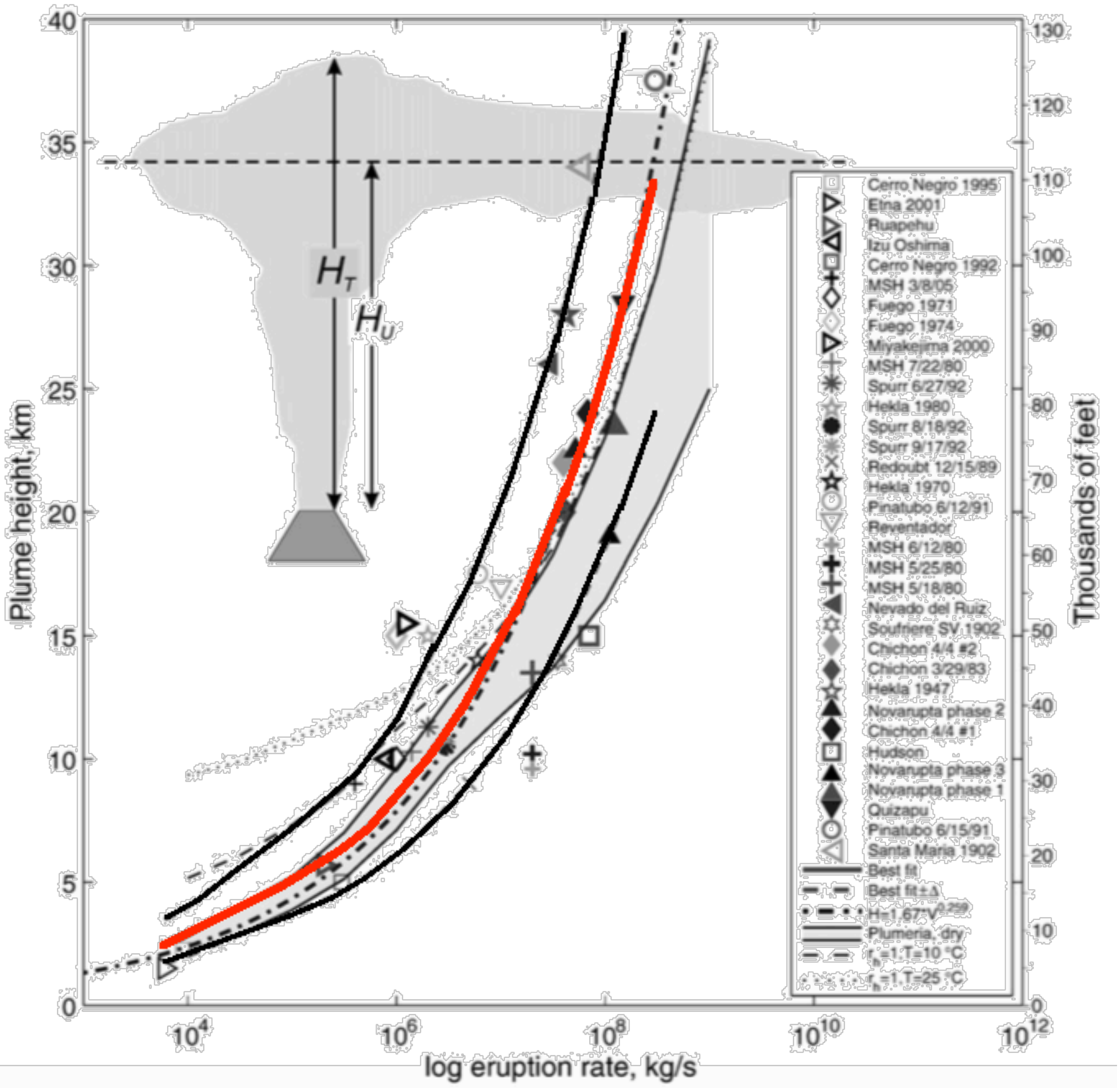
In this exercise you will reproduce the plot "$\log_{10} MER\ vs. Height$". In this exercise you will thus vary the MER at the vent, keeping fixed the exit velocity at the vent. In order to do so, set "radius = 0" and just vary the "Mass eruption rate at the vent" (as shown in the figure below).

```
% Eruption initial conditions
    3200    % Vent height a.s.l [m]
    300     % Plume velocity [m/s]
    1400    % Plume temperature [K]
    0.97    % Mass fraction solid phase
    0       % Mass fraction liquid phase
    0.03    % Mass fraction dry air phase (water vapor is the complementary to 1 of the sum of all the phases)
    46.20   % Vent latitude
    -122.18 % Vent longitude
    700     % Diffusivity in the plume (for sedimentation)
    1000    % Density of liquid water in the plume [kg/m^3]
    2350    % Density of solid particles in the plume [kg/m^3]
    1e8     % Mass Eruption Rate at the vent [Kg/s]
    0       % Plume radius: 0 = dir. MER; otherwise indir. MER
    0.0098  % 0 no condensation., 1/(2.8*3600)=9.9206e-005 moderate, 1/(1.7*60)=0.0098
    1E+8    % Total mass erupted [kg]
% Working folder and meteo profiles
    Exercise2p4 % Name of the folder for the single run
    windprofile     % Name of the wind profile: IT MUST BE IN THE FORMAT [km , m/s]!!!
    temperatureprofile      % Name of the temp profile: IT MUST BE IN THE FORMAT [km , C]!!!
    txt     % Extention of files in the "runs" folder
```

Fill the following table

MER (kg/s)	**Height of the erupted column (km)**
10^4	
$5 \cdot 10^4$	
10^5	
$5 \cdot 10^5$	
10^6	
$5 \cdot 10^6$	
10^7	
$5 \cdot 10^7$	
10^8	
$5 \cdot 10^8$	
10^9	

Overlap your points in the "$\log_{10} MER \ vs. Height$" plot of Mastin et al. (2009) shown below (the red line is the best fit, the two black lines are the one sigma lines).



Question 12: Which comments can you make between the overlap of your points and the lines in the plot? Are they in good agreement with the Mastin's fit ($H(km) = 0.304 \cdot MER^{0.241}$)? The fact that the plume height (expressed in km) is related to the MER by $H(km) \propto MER^{1/4}$, which consequences has on the error in estimating the MER (explain qualitatively, not quantitatively)?