Tephra2 Workshop

June 30th, Melbourne

Leah Courtland
University of South Florida
courtland@mail.usf.edu

Worksheet

I. Outline: The Tephra2 hands-on portion of this workshop will cover the following:

a. Practical Introduction to Tephra2
b. Discuss and explain the input parameters
c. Run the program using Cerro Negro Volcano as an example
d. Analyze program output
e. Introduce the student version which can be useful in teaching less advanced students
f. Concluding Remarks

If you have questions, feel free to interrupt: there is no need to wait until the end!

In the hand out, directions which require an action on the part of the user are indicated in **<u>bold and underlined</u>**.

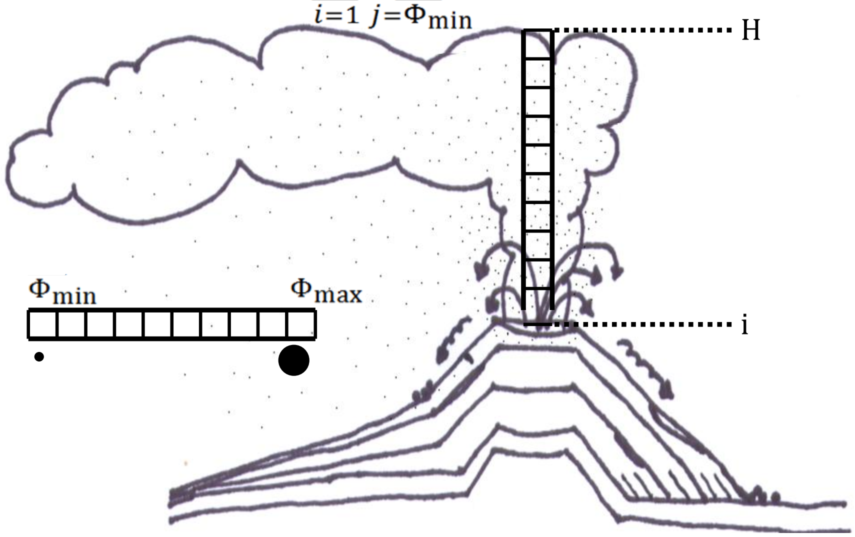
II. A Practical Introduction

What is Tephra2?

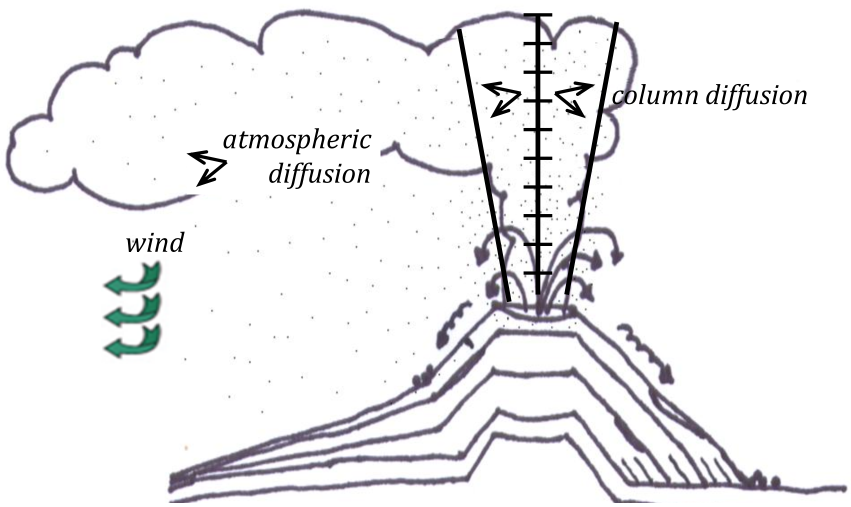
Tephra2 is a program which uses the advection-diffusion equation to calculate the mass loading of tephra on the ground. It can be used to create an ashfall hazard map for a volcano or to probe the amount of ashfall to be expected at a single location, either under average conditions or in a worst case scenario. The model result can be used to examine the spatial distribution of volcanic particles of various sizes. Additionally, Tephra2 is an example of the usefulness of calculus and numerical modeling both in gaining a better understanding of natural processes and as practical tool for disaster management planning. In addition to its application to volcanological research and hazard mitigation, Tephra2 may be used in the classroom to teach about volcanology, disaster management, numerical modeling, or calculus applications.

The code works by taking a user supplied set of eruption parameters and applying the advection-diffusion equation to calculate the mass loading of particles on the ground. This involves performing a double integration at each grid location. This is represented pictorially below:

$$M(x,y) = \sum_{i=1}^{H} \sum_{j=\Phi_{\min}}^{\Phi_{\max}} M_{i,j}^{0} \, f_{i,j}(x,y)$$



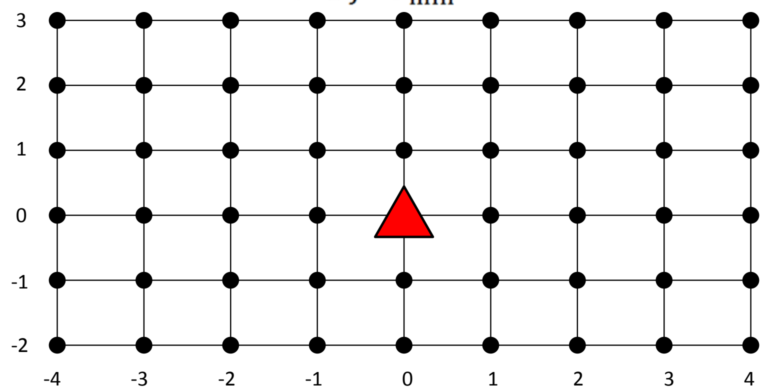
For each step up the eruption column (i), from the vent to the maximum column height, each grain size (j) is considered. Tephra2 calculates the probability of particle release at each step. Once a particle is released, the particle fall time is calculated based on the point of release.



Particle movement is modified by both column diffusion and atmospheric diffusion. Particles fall through a layered atmosphere, with layers characterized by different wind velocities. In this manner, mass is accumulated at each grid location.

The function f (below) describes this advection-diffusion.

$$M(x,y) = \sum_{i=1}^{H} \sum_{j=\Phi_{\min}}^{\Phi_{\max}} M_{i,j}^{0} \, f_{i,j}(x,y)$$



$$f_{i,j}(x,y) = \frac{1}{2\pi\sigma_{i,j}^{2}} \exp\left(-\frac{\left(x-\bar{x}_{i,j}\right)^{2} + \left(y-\bar{y}_{i,j}\right)^{2}}{2\sigma_{i,j}^{2}} \right)$$

After Tephra2 completes its calculations, it outputs the mass per unit area of tephra at each of the supplied locations. This information can be contoured in order to create an Isopach map or converted from mass over area to thickness in order to study the propensity for roof collapse, for example. In addition to the total mass of tephra at each location, the program also outputs the size distribution of tephra. This information might be important when considering the health effects of ash inhalation on humans, for example.

This model does not include the effects of particle agglomeration. Additionally, it drastically under-predicts ultra-proximal tephra accumulation where other modes of deposition, such as ballistic emplacement, pyroclastic flows, and fallout from plume margins, contribute greatly to the deposit.

Other assumptions include the simplification of the wind field such that wind velocity in each atmospheric layer does not change with distance. This approximation works very well for small eruptions, but may not apply to very large eruptions in which the eruption cloud spreads out over great distances.

The particle size distribution is approximated as a Gaussian distribution and cannot be used to model bi-modal distributions.

More information on the background and utilization of tephra2 can be found in the supporting documents section of the Vhub Tephra2 online simulation tool. (http://vhub.org/resources/26/supportingdocs). Specifically, most of the information contained in this workshop can be found in the Tephra2 manual and video tutorials posted on this sight.

III. Running Tephra2: Inputs:

Tephra2 was originally designed as a command line tool. If you are interested in running Tephra2 at the command line, instructions on how to do so are included at the end of the Tephra2 tutorial 2, as well as in the Tephra2 manual.

In today's workshop we will run Tephra2 online via the Vhub simulation tool. In order to run Tephra2 or any other Vhub online simulation tool, you must have a Vhub account. If you do not already have an account, you can create one in just a few moments by selecting the registration link from the Vhub home page.

To start the tool, go to resource warehouse, online simulation tools, Tephra2. Here you will find a brief overview of the program, the appropriate citation, the user manual, and other helpful documents. **Before launching the tool, please select 'View all Supporting Documents'**. This is where the manual, video tutorials, and various scripts associated with tool input and output are located.

Tephra2 requires three input files: a grid file, a wind file, and a configuration file. Although the graphical user interface contains examples of each of these files, let's instead make ours from scratch.

We will start with the grid file. I am choosing to use the supplied perl script to create the grid. However you could create this text file in C, Matlab, or any number of other programs as well. If you are following along and you do not have perl installed on your computer, please be aware that the files which we will be creating are also pre-loaded into the GUI as examples and so it is not necessary for you to re-create them yourself in order to use the tool.

From the tephra2 supporting documents, open the file 'create_grid.conf'. This file contains the parameters necessary to create a grid file. The first three values are volcano northing, volcano easting, and elevation. We will be modeling an eruption at Cerro Negro Volcano which is located at:

Northing: 1382690
Easting: 532290
Elevation: 500

Please enter these parameters into the perl script. Note that elevation here is the elevation of the surrounding territory and not the elevation of the vent itself. That will be supplied in the configuration file. Also note that the script will create a grid of points all located at a single elevation. Testing of tephra2 has shown that calculations are more accurate when performed over a grid of constant elevation. If there is significant topography at your site, we recommend performing calculations over a constant elevation grid and then draping the result over topography during post-processing.

The desired grid size will depend on the size of the eruption to be modeled. Larger eruptions will deposit tephra over larger areas and so will require larger grids. Strong winds can also cause tephra to be deposited at locations far from the volcano and so will require a larger grid than if material is ejected into a quiescent atmosphere.

Enter the minimum and maximum locations where you would like tephra accumulation to be calculated. For Cerro Negro we can use values of

Min_East 480000
Max_East 580000
Min_North 1430000
Max_North 1330000

The script we are working with is designed to create a radial grid about the volcano. The writers of Tephra2 found that this type of grid resulted in the cleanest contour plots during post processing.

The parameter grid_step indicates how densely to place points on each ring. A value of 100 indicates that a grid point will be placed every 100 m along each ring.
The parameter num_rings tells the program how many rings to create.
Finally, the spacing parameter refers to the spacing between rings, in meters.
We can leave all of these parameters as they are.

Save the file. Also download and save the file 'create_grid.pl' into the same directiory. Running the file create_grid.pl will read the parameters file in order to create a grid file. **To run the file, type perl create_grid.pl** .The output file is titled 'grid.in'. Open this file. Here you can see the format expected by the Tephra2 program. This format is

EASTING NORTHING ELEVATION

If using a different program to create your input file, or if you are only interested in tephra accumulation at discrete points, be sure to save the grid file in this format. We will upload this file into the GUI after launching the Tephra2 tool.

Next we will need to prepare a wind file. We could go to the REANALYSIS website to download a specific wind field, but for this workshop we will just write one out based on what we know about the area. Directions on how to download REANALYSIS data can be found in the Tephra2 supporting documents.

Strong trade winds blowing to the southwest tend to characterize the weather patterns at Cerro Negro, and so for this file I will enter a constant wind field that blows towards the southwest. The format of this file is:

ELEVATION SPEED DIRECTION

For Cerro Negro, I will enter

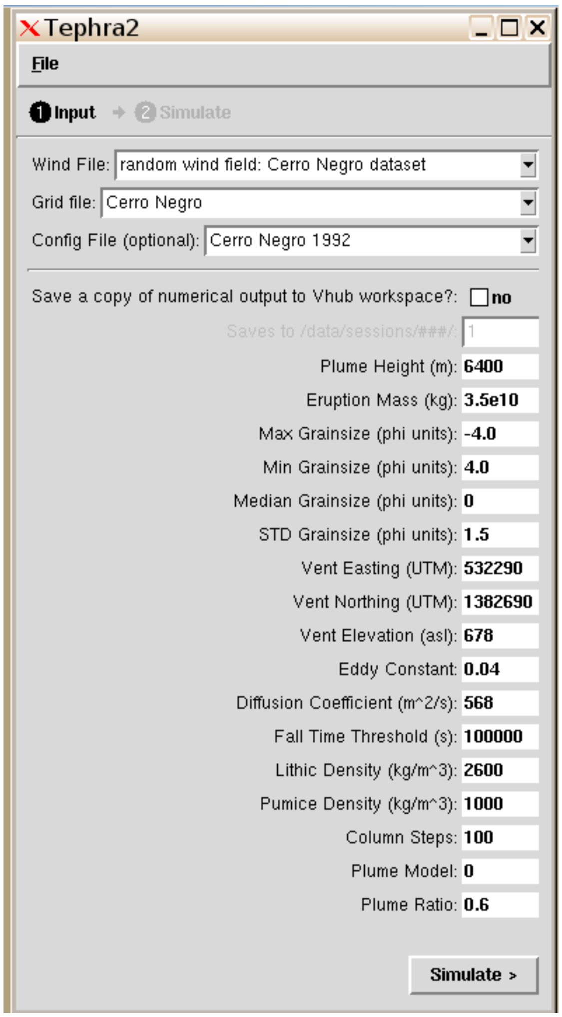
114 12.5 250
792 16.7 250
1515 15.1 250

3145 12.9 250
4408 11.0 250
5859 10.3 250
7573 10.5 250

Now we are ready to launch the tephra2 online simulation tool. **<u>Press 'launch' to open the GUI</u>**.

<u>Select a language and hit 'Simulate.'</u> We will now enter the configuration parameters into the GUI. Although we could just as easily save all of these parameters in a text file as we did the grid and the wind, we will use the GUI instead so that we can practice tweaking the parameters from within this interface.

<u>Enter the parameters visible in the screenshot below into the user interface.</u>



- The first parameter is the plume height, in meters. Here you enter the maximum plume height of the eruption you wish to simulate.
- Next is the total mass of pyroclastic material ejected from the volcano, in kg. Do not include mass due to any material which may have been extruded as lava or deposited as pyroclastic flows.
- The maximum, minimum, and median grain sizes of tephra erupted from the volcano should be entered in phi units. (suggested limits: -6 : 6 phi)
- The standard deviation of the grain size distribution should also be entered in phi units. The total grainsize distribution will be modeled as a Gaussian distribution and this parameter describes the width of that Gaussian.
- The volcano location is given in UTM coordinates.
- The eddy constant describes atmospheric diffusion. For Earth's atmosphere the value is 0.04.
- The diffusion coefficient describes the advection and diffusion of particles through the atmosphere. In our experience, constants varying from 100 to 10,000 have been found to be reasonable.
- The fall time threshold sets the boundary between particles which obey a linear diffusion law (larger particles, shorter particle fall times) and those which obey a power law (smaller particles, larger particle fall times).
- The lithic density refers to the density of small, dense particles. The pumice density refers to the density of larger, less dense particles. Both values are given in kg/m^3.
- Column Steps refers to the number of segments into which to discretize the eruption column. For example, a value of 100 would indicate that the model is to split the column into 100 vertically stacked layers, each of which lies in the horizontal plain.

- Plume Model describes the distribution of mass within the eruption column. A value of 0 corresponds to a well-mixed plume. In such a model, particles of all sizes are released from every release height.
- Finally, the plume ratio sets the minimum particle fallout height. For example, a value of 0 would indicate that particles are released the entire column. A value of 0.7 indicates that particles are only released from the upper 30% of the column. The value of this parameter should be between 0 and 1. However, entering a value of 1 will result in error, so if you want particles to be released only from the top of the column, it is best to enter 0.999 instead.

Before running the model, we need to load our grid and wind files into the GUI. To do so, simply **click each field and select 'Upload. . .' A pop-up window will appear from which you should be able to navigate to the location where you stored each file.** Make sure that you have enabled the use of pop-ups from the Vhub site.

If you were unable to create these files during the workshop, you can instead load one of the example files. Since we are modeling the 1992 eruption of Cerro Negro Volcano, you will want to upload the Cerro Negro grid. The wind file that we are using is similar to the example file titled 'constant from the Northeast'.

Note that the wind field loader also has the option of loading a random wind field. The interface has access to over 300 wind fields sampled in the vicinity of each example volcano over a period of a year. With the random wind field option selected, the program will randomly use one of these wind fields in performing calculations.

Finally, note that you have the option of uploading a configuration file. Selecting the Cerro Negro example will insert the values that we entered above. Uploading a configuration file from home will not automatically fill in these fields; however calculations will be performed on the uploaded file regardless.

Hit 'Simulate' to run the program.

IV. Output

Once Tephra2 finishes its calculations, it will create an Isopach map of the results. The quality of this map will vary. For best results we recommend downloading the code output and recreating these maps for yourself. This way you can set the proper map limits and contour line intervals, add topography, etc. The combination of perl and gmt commands used to create the map provided by the tephra2 simulation tool may be found in the supporting documents.

Clicking on the result field allows you to select other outputs for viewing. **Select 'Tephra2 Output'**. This shows you the actual numerical result of the Tephra2 code. To save the Tephra2 output to your personal computer, you may either select 'download' from the Results drop down menu or click on the little green arrow just to the right of it. Select "ok" in the popup window that appears. This will download whichever file is currently visible in the GUI output.

Now let's say that I want to run the model again, altering one or more parameters. **Simply click the "Input" button in the lower left to return to and alter the input parameters. Change whatever parameters you wish and hit simulate**. To toggle back and forth between the output of each run, simply select a run from the bar at the bottom. There is one catch to re-running a simulation. If you wish to run the simulation with identical configuration parameters and a new random wind field and so hit the "Input" button followed by the "simulate" button, the GUI will not recognize this as a new simulation and so will simply display the results from the previous simulation. In order to perform the simulation with a different wind field, you will first need to clear the results, and then return to the inputs. Unfortunately, this means that you cannot toggle between outputs. However, if you save each run to your computer, you will be able to view differences in code output on your home computer even if you are unable to view them via the GUI. Alternatively, an alternate work around would be to change one of the parameters by a single digit as this have minimal affect the calculation but will alert the GUI to process the new inputs.

The format of the numerical output is

Easting   Northing   Elevation   Mass/Area   % Phi

Continue reading to see how to spice up the contour plot, or skip to the next section to see how to use the student version of Tephra2.

Now let's try spicing up this contour plot. **Download the script 'make_contour_plot.pl'. Open this file.** At the top you will see that, in order to execute this script, you need to have perl, proj, and GMT installed. Please note that if you do not have these programs installed on your home computer you could upload the files to your vhub workspace and run them on the hub.

This script invokes two text files: vents.ll and cities.ll. These files store the location of vents and cities to plot on your Isopach map. The format of these files is

latitude   longitude   text size   text angle   font number   justification   text

For Cerro Negro, we can **open a text file and enter the following in order to create the vents.ll file**:

-103.620 19.514 8 0 22 RB V Colima

And the cities.ll file:

-103.717 19.233 8 0 24 LT Colima

The third file called by this program contains information about which contours to plot and is called contours. **Download the example contour file contained in the supporting documents tab. Open the file and change the value of any of the contour lines.** Now we are ready to execute the script. **Type perl make_contour_plot.pl into the command line.** This will create a .jpg file with the contours you requested, the cities and vents you identified, and any rivers or other features identified by pscoast.

V. Student Version

There is another online simulation tool, called Tephra2: Education Mode, that utilizes the Tephra2 program for educational purposes only. Model inputs are far more constrained than in the regular Tephra2 tool. This version has been designed for students use and does not require much background knowledge in either volcanology or numerical modeling.

Go to resource warehouse, online simulation tools, Tephra2: Education Mode and launch the tool. In this version, the user does not have the option of uploading their own data and instead must work with one of the example volcanoes. We will investigate the Colima example.

Select Colima for the volcano and Random Wind Field: Colima for the wind. Alternatively, you could set a constant wind field if you wish to see how altering individual parameters affects the deposit.

Select an eruption type. The defaults of the eruption parameters that appear in the first tab, as well as their bounds, depend on which eruption type you selected. For example the default Eruption Mass for a Strombolian eruption is much less than that of a Plinian eruption.

Select the Particle Parameters Tab Students may alter the grain size information within the Particle Parameters tab, where they can also set the density of particles.

Select the Simulation Parameters Tab. The Simulation Parameters tab allows students to change some aspects of the model. You will notice that certain parameters, like the particle fall time, are set behind the scenes so that students do no need to worry about them. Changing the Particle Release height alters the pictorial description of the model presented in this tab. We believe that this gives students a better understanding of the meaning of this parameter.

Finally, select the images tab. Here you will find educational materials not strictly necessary to run the model. For example, a picture of the volcano which is included in order to remind students that they are modeling an eruption at a real volcano and not just entering random numbers into a computer. Also included is a location map. The code output will be overlain on this location map once calculations have finished, however it can be beneficial for students to see the map before hand in order to start thinking about the proximity of the volcano to population centers and water reserves, for example.

As with the Tephra2 tool, **select Simulate** to run the model. Output includes an Isopach map with topography and other information, the numerical results, and a copy of the input configuration file.

Finally, we would like to mention that under the supporting documents of the educational tool you will find a laboratory exercise written for an undergraduate natural hazards class. This lab utilizes the Tephra2 education model to teach students about probability, histograms, etc.

VI. Concluding Remarks

This concludes the Tephra2 workshop worksheet. Hopefully it has helped you to learn how to utilize the Tephra2 program in your own work. Please remember that this program is open source and can be downloaded from the Offline Simulation Tools section of Vhub.

Papers Discussing Tephra or Tephra2

Bonadonna, C., C.B. Connor, B.F. Houghton, L. Connor, M. Byrne, A. Laing, T.K. Hincks, 2005, Probabilistic modeling of tephra-fall dispersal: hazard assessment of a multiphase rhyolitic eruption at Tarawera, New Zealand, Journal of Geophysical Research, Vol. 110, No. B3, B0320310.1029/2003JB002896.

Connor, C. B., Hill, B. E.,Winfrey, B., Franklin, N.M., and LaFemina, P. C.: Estimation of volcanic hazards from tephra fallout, Natural Hazards Review, 2, 33–42, 2001.

Connor, L.J., and C.B. Connor, 2006, Inversion is the Key to Dispersion: Understanding Eruption Dynamics by Inverting Tephra Fallout, in: H. M. Mader, S. Coles, C.B. Connor and L.J. Connor (eds), Statistics in Volcanology, IAVCEI 1, Geological Society of London, 231-242.

Scollo, S., Folch, A., and Costa, A.: A parametric and comparative study on different tephra fallout models, J. Volcanol. Geoth. Res., 176, 199–211, 2008b.

Scollo, S., M. Prestifilippo, G. Spata, M. D'Agostino, and M. Coltelli (2009), Monitoring and forecasting Etna volcanic plumes, Nat. Hazards Earth Syst. Sci., 9, 1573–1585, doi:10.5194/nhess-9-1573-2009.[CrossRef]

Scollo, S., S. Tarantola, C. Bonadonna, M. Coltelli, and A. Saltelli (2008), Sensitivity analysis and uncertainty estimation for tephra dispersal models, J. Geophys. Res., 113, B06202, doi:10.1029/2006JB004864.[AGU]

Scollo, S., Tarantola, S., Bonadonna, C., Coltelli, M., Saltelli, A., 2008. Sensitivity analysis and uncertainty estimation for tephra dispersal models. Journal of Geophysical Research 113 (B06202). doi:10.1029/2006JB004864. Andrea, Sensitivity analysis and uncertainty estimation for tephra dispersal models, in press in JGR.

Volentik AMC, Bonadonna C, Connor CB, Connor LJ, Rosi M (2010) Modeling tephra dispersal in absence of wind: insights from the climactic phase of the 2450 BP Plinian eruption of Pululagua volcano Ecuador). J Volcanol Geotherm Res 193:117–136