Tephra2 Tutorial Scripts

By Leah Courtland

Tephra2 Tutorial 1: An Introduction

This video will introduce you to the concepts behind the tephra2 online simulation tool.

Tephra2 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, to probe the amount of ashfall to be expected at a single location, or 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 a practical tool for disaster management planning.

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. 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, 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.

Here are the input parameters as they appear in the graphical user interface. These parameters provide the program with information about the location and size of the eruption, the local wind field, and other relevant information. I will now go over each parameter individually.

- 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.
- 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 of easting, northing, and elevation.

- The eddy constant describes atmospheric diffusion. The eddy constant of the Earth's atmosphere is 0.04.
- The diffusion coefficient describes the advection and diffusion of particles through the atmosphere.
- The fall time threshold is the maximum time limit by which particles need to land. If particles have not landed by this cutoff time, the model will stop calculations and said particle will not be added to the mass accumulation of tephra on the ground. Note that this is time within the volcanological problem, not run time of the computation.
- 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.

- 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 point.
- Finally, the plume ratio sets the minimum particle fallout height. For example, a value of 0 would indicate that particles are released from the entire column. A value of 0.9 indicates that particles are only released from the upper 10% of the column, while a value of 0.2 indicates release from the upper 80% of the column. The value of this parameter should be between 0 and 1.

All of the inputs I just described are input to the model and loaded into a single configuration file.

Two additional files are required in order to run tephra2: one describing the local wind field and another containing all of the locations at which the user would like tephra2 to make calculations. The format of all three of these files will be covered in more detail in Tutorial 2.

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 and in fact tephra2, when run via the GUI, will contour the data automatically and create a rudimentary Isopach map for the user. I say rudimentary as the values of the visible isopachs are determined by the code and no geographical information, for example topography, the location of population centers, or water sources, or other factors are not included.

In addition to the creation of Isopach and tephra hazard maps, the mass per unit area values output by the code may be converted to thickness in order to study such things as the propensity for roof collapse. In addition to the total mass of tephra at each location, the program also outputs the size distribution of particles at each location. This information might be important for someone investigating possible health effects related to an eruption as small particulates are easily inhaled and are known to cause respiratory problems.

This model does not include the effects of particle agglomeration. Additionally, it drastically under-predicts ultra-proximal (<13 km) tephra accumulation where other modes of deposition, such as ballistic emplacement, pyroclastic flows, and fallout from plume margins, may contribute greatly to the deposit.

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

Another simplification is that the distribution of the diameter of pyroclastic particles has a single mode. Many deposits have in fact been found to have bi-modal distributions. However, even in these eruptions, it is often the case that one mode dominates over the other, suggesting that approximating such a distribution with a single mode is a valid approach.

This concludes tutorial one. The script for this and other tephra2 tutorials may be found under the supporting documents tab of the tephra2 online simulation tool.

Tephra2 Tutorial 2: Running Tephra2

This tutorial goes through the steps necessary to run tephra2 both online via the vhub graphical user interface as well as on a personal computer via the command line.

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 as well as the user manual, and many other helpful documents. To start the tool, click the launch tool button. This will bring up the graphical user interface.

Tephra 2 requires three types of inputs: The eruption parameters, also referred to as configuration information, the wind information, and the topography or grid information. We will go over each of these in turn.

In this example, we will attempt to model the 1992 eruption of Cerro Negro volcano, Nicaragua. This example is also available through the online tool simply by selecting Cerro Negro from the appropriate fields.

First, we must supply a file which describes the local wind activity. The format of this file is height, in meters, wind speed, in m/s, and finally direction, from 0 to 360 degrees with both 0 and 360 describing wind that blows towards the north and 180 degrees describing wind blowing towards the south. For example, the first line of this wind field says that at an elevation of 1000 meters, the wind is blowing towards the west at 7.7 m/s. It is a good idea for your wind file to have values extending to a height above your maximum column height. One way to obtain wind field data is to download reanalysis data. For more information on how to do this, please see the appropriate file in the online simulation tool supporting documents.

Although the Cerro Negro average wind field is already pre-loaded as the constant wind field in the examples, we will instead upload the file we were just looking at in order to see how it is done. Selecting browse and I navigate to the wind field on my personal computer and upload the file.

Next we need to supply tephra2 with a grid file. This is a collection of all of the points for which tephra2 will calculate the mass accumulation of tephra. Here is an example file. The format is Easting Northing Elevation above sea level. Testing has shown that the code works best for grids of constant elevation. Thus we recommend that your grid file contain no topography. If significant topography is present in your study area, we recommend performing the calculations on a grid of no topography and then draping the results over the topography once calculations have completed. We can upload the grid file in the same manner as we did the wind file. Alternatively, if we only wanted to make calculations at a single point or a few points, we could just type in Easting Northing Elevation into this area here however in most cases you will want numerous locations about a volcano and you will be uploading files.

The size of this file will affect the length of time tephra2 takes to complete its calculations. This is because it takes longer to calculate the accumulation of tephra at a large number of points than it does to perform the calculation for only a small number of points. A perl script which generates a decent grid file can be found in the supporting documents section of this tool.

Now that we have loaded a wind file and a grid file, we need to work on the configuration file. There are two possibilities here. We can either upload a configuration file the same way that we did the wind and grid files, or we may fill in the fields below and allow the program to create this file for us. Here is an example of how the configuration file will look. Notice that it consists of a series of keywords followed by their values. Instead of uploading this file, we will type this information into the user interface and allow the program to create the configuration file for us.

- The first parameter is the plume height, in meters. Enter the maximum plume height of the eruption you wish to simulate. I am entering 6,400 meters for the Cerro Negro 1992 eruption.
- Next we enter the total mass of pyroclastic material ejected from the volcano, in kg. The Cerro Negro 1992 eruption resulted in a fallout deposit corresponding to a mass of approximately 3.5x10^10 kg.
- The maximum, minimum, and median grain sizes of tephra erupted from the volcano should be entered in phi units. In case you don't remember, phi = -log base 2 (mm). Ash is in the range 1-8+ phi, lapilli 0:-6 phi, and blocks and bomb have sizes greater than -6 phi. Good values for the eruption we are attempting to model might be -4 to 4 phi with a median grain size of 0 phi. Particles smaller than 4 or 5 phi tend to aggregate and fall in clumps, a process not modeled by Tephra2. Typical values for minimum and maximum phi appropriate for the tephra2 model range from 6 to -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 and this parameter describes the width of that Gaussian. I am entering a width of 1.5 phi.
- Next we will enter the volcano location in UTM coordinates. Cerro Negro is located at an Easting of 532290, and 1382690 Northing, and an elevation of 678 meters above sea level.
- The eddy constant describes atmospheric diffusion. The value for the Earth's atmosphere is 0.04
- The diffusion coefficient describes the advection and diffusion of particles through the atmosphere. A realistic value for the diffusion coefficient of the atmosphere is 100 m^2/s. However, higher values are often used in modeling to account for variations in the eruption column over time as well as atmospheric variations that occur over the course of the eruption. In our experience, constants of 100 to greater than 10,000 have been found to be reasonable. For Cerro Negro, I will use a value of 570.
- The fall time threshold is the maximum time limit by which particles must land. If particles have not landed by this cutoff time, the model will stop calculations and said particle will not be added to the mass accumulation of tephra on the ground. For Cerro Negro I will use a value of 100,000. However, if I was modeling an eruption consisting of many smaller grains or of a taller eruption column I might need to increase that threshold in order to give particles enough time to land.
- The lithic density refers to the density of small, dense particles. For Cerro Negro I am entering a value of 2600kg/m^3.
- The pumice density refers to the density of larger, less dense particles. Both values are given in kg/m^3. For Cerro Negro I will use enter a value of 1000 kg/m^3. For many eruptions it may be unnecessary to make this distinction. If that is the case, simply enter the same value into both fields.
- Column Steps refers to the number of segments into which to discretize the eruption column. In other words, if the eruption column is broken up into segments each of height dz, the Column steps parameter corresponds to the number of dz segments present in the entire column. A value of 100 is sufficient in most cases.
- The Plume Model parameter 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 point.
- Finally, the plume ratio sets the minimum particle fallout height. For example, a value of 0 would indicate that particles are released from the entire column. A value of 0.9 indicates that particles are only released from the upper 10% of the column while a value of 0.1 indicates particle release from the upper 90% of the column. The value of this parameter should be between 0 and 1. However, entering a value of 1 will result in errors, so if you want particles to be released only from the very top of the column, it is best to enter 0.999 instead.

We have now entered all of the information necessary for the tool to create our configuration file. If you instead choose to upload your own config file, see the tephra2 manual for the exact spelling of the keyword parameters as they differ slightly from what appears in the graphical user interface. Also, be aware that, if you select one of the examples it will automatically load all of the values into the user interface, while if you upload your own personal file none of those values will be visible. However, the code will use your supplied values in making its calculations and you will be able to double check that because the inputs are also included as a separate output file as I'll show you in a moment.

At this point we are ready to run the model. To do so, simply hit simulate here at the bottom. The amount of time it takes tephra2 to complete calculations depends on the inputs you prepared. Models with many column steps and many points to calculate may take some time to run. Luckily, even if you are forced to shut down your local machine, vhub's computers will remain on and your session will remain open whether you are logged in or not.

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. The numerical output is available by selecting the results bar, tephra2 output. This is what the tephra2 program actually creates. This file contains your grid locations, Easting, Northing, and Elevation, followed by the total mass at that location, and then the percent of each of these phi ranges present at that location.

In order to download this, you simply select download or you can hit the little green arrow off to the side. Now you can choose either to open it on our home computer or to simply save the file. Hit save file, select okay, and you're done.

The download procedure will save whatever file was loaded into the output file at the time. Now, as promised, the input parameters are included in the output window, in case there was any doubt as to which parameters you input to the model.

Now let's say we wanted to change one of these parameters and run the model again. All we have to do is select input and make a change. How about we see what happens with a different wind field. We will use a random wind field. These random wind fields were actually collected at Colima Volcano but let's just see what happens when we run this simulation. So once again Tephra2 is performing calculations at every grid location. You can see that by the text output to the screen while the simulation is running and in a moment the contour map will be automatically created.

I want to note that one of the important reasons why you might want to download the numerical results and redo the contour map is that then you can choose perhaps more logical contour lines, you can change the limits of the map, you can add cities and water resources and other important features such as topography.

So here is our new result, we can see that it looks very different from the first. We have the ability to toggle between results. You can see that here it's telling us what the wind was and attempting to display that file that we uploaded and here it's telling us that we used a random field.

Now that we understand how to run tephra2 online, I would like to go over how to download the source code and run the program on a personal computer via the command line. The source code is provided as a separate tool located here in the offline tools section. Tephra2 source code. Now if we simply select the download button it will download the default file which is the linux version of Tephra2. You also have the option to download the cygwin version which is located under the supporting documents. To download the files, simply select download and save the file.

To run the file, we need to unzip it so: tar xvf tephra2.tar.gz enter. Now we can see that we have created the tephra2 folder, let's get into the documents structure and here we need to run make, type make, and we have built the program and now we can see the tephra2 executable. Next step you need to copy the wind file, configuration file, and your grid file into the same directory as the executable.

In order to run the code, simply type: ./tephra2 config.file grid.file wind.file > tephra2_output.txt tephra2. The output will be stored in the current directory.

In this version, the input parameters appear here on the screen after you press enter. This version is numerically equivalent to the version which runs on the hub.

We can look and see that our output file has appeared. Just to check I will do: more tephra2_output.txt, enter, and there are values in that file so that was a successful run. The next step would be for me to do something with this file, I could contour it, I could sum up all the mass and make sure that it was the same amount that I threw out, which it should be, or whatever else I wanted to do with it.

This concludes tutorial 2. The script to this and other tephra2 tutorials is located in the supporting documents section of the tephra2 online simulation tool.

Tephra2 Tutorial 3: Example with Analysis: Colima

In this tutorial I will show you an example of how to run the tephra2 tool using your own data. I will assume that you have a general understanding of code execution including knowledge of the necessary inputs and outputs.

For this example I will attempt to model a plinian eruption at Colima volcano.

First I must prepare my configuration file. I can do so either within a text file or by typing the parameters into the graphical user interface. I will use the graphical user interface.

- The plume height for a plinian eruption might be 25 km
- The mass of material ejected during such an eruption might be 5 x 10^11 kg of material
- For maximum grain size I am using -6 phi, min: 6 phi, median: -.5 phi, STD: 1.8 phi
- The Easting of Colima Volcano is 644804, Northing: 2158284, Elevation: 4330
- The eddy constant of the atmosphere is 0.04.
- The diffusion coefficient that I will use for this eruption is the value of 2000 which will allow for some variability in the eruption. One thing I would like to note that tephra2 has not been found to be particularly sensitive to this parameter, and so the fact that we don't know its exact value is not going to hold us back too much when we go to simulate eruptions.
- I will use 1,000,000 as the fall time threshold.
- I will set the pumice and lithic densities both equal to 2500 kg/m^3.
- I will have the model break up the column height into 100 vertical segments.
- I enter 0 for the plume model so that the column will release particles of all sizes from all release points.
- Plinian columns are characterized by an umbrella region. In such eruption, the majority of the mass is released from the upper 10 % of the column and so I will enter a value of 0.9 for the plume ratio.

Next I need a wind file. I am going to use this default random wind file. This option actually chooses between over 100 wind files all extracted from Reanalysis data collected in the vicinity of Colima volcano randomly sampled over a one year period.

The only thing left is the grid file and so I want to show you how to make your own file for use in the tephra2 program. If you go to the supporting documents section, you will see a number of supporting documents. The two files create_grid.conf and create_grid.pl are necessary to create a grid for use with tephra2.

This is the file create_grid.pl but to use it you will not alter the script itself, instead you will alter the file create_grid.conf. Here we have the volcano's Easting and Northing, and this is the elevation of the grid (not the vent). This file is set up to create a grid of constant elevation, all of the points will be at the same elevation, which we have found to be a more accurate surface onto which to collect the mass ejected from the volcano. These other parameters dictate the size and spacing of the grid. This creates a circular grid. Here we have the number of rings to be created, the minimum and maximum northing and easting locations, the spacing of the grid, etc.

Now to create the grid file we will type 'perl create_grid.pl>Colima.grid'. Now we need to upload this new file into the graphical user interface for tephra2. So now we have a wind file, a grid file, and this here is a configuration file. So I will go ahead and simulate this eruption.

Now after these calculations have finished we will see an automatically generated Isopach map, numerical output, and the input configuration file.

Instead of using the Isopach map provided by the tephra2 tool, we will download the raw data and try messing around with it. I press the download button and save the file.

Now that I have downloaded the numerical output I need to have the two files: make_contout_plot.pl, parse_tephra_out.pl. These will allow me to create my own Isopach map.

This is the script for the Isopach map. Here we type in the name of the data file that we'll be using. If we want to label various vents on this map we need a file with the vent names, if we want to locate the cities we need a file with the city names and locations, and then we have a contour file which tells us where to make contour lines. Lines with an 'a' next to them will be plotted in bold and labeled and the others will appear without labels. If we want to include topography we need to inform the program where our topography files are located. I am using files derived from SRTM data. The default color palette is gray however you can also use your own, uniquely defined color palette if you prefer. Additionally, you will need to enter the map limits, in latitude and longitude, here.

In order to run this program you must have perl, gmt, and proj installed on your computer. To run the script, type: perl make_contour_plot.pl. If you are missing any of these files like the vent file, the cities file, or even the topography file, the program will go ahead and create as much of this map as it can.

This is just one example of how you might go about analyzing data that was output by the Tephra2 numerical model.

This conclude Tutorial 3. The script for this and other tephra2 tutorials may be found under the supporting documents tab of the Tephra2 online simulation tool.

Tephra2 Tutorial 4: Mathematical Concepts

Tephra dispersion models based on the advection diffusion equation predict the amount of mass accumulation at geographic locations based on a set of eruption parameters.

The numerical simulation of tephra accumulation can be expressed by a simplified mass-conservation equation of the type shown on this slide

$$\frac{\partial C_j}{\partial t} + w_x \frac{\partial C_j}{\partial x} + w_y \frac{\partial C_j}{\partial y} - v_{l,j} \frac{\partial C_j}{\partial z} = K \frac{\partial^2 C_j}{\partial x^2} + K \frac{\partial^2 C_j}{\partial y^2} + \Phi$$

Here *x* is positive in the mean downwind direction, *y* is the mean cross-wind direction, and *z* is vertical;

w_x and w_y are the *x* and *y* components of the wind velocity, in m s^{-1}. Vertical wind velocity is assumed to be negligible.

C_j is the mass concentration of particles, in kg m^{-3}, of a given particle size class, *j*. In this image, we can see that the smaller particles are more densely concentrated than the larger particles.

K is a horizontal diffusion coefficient for tephra in the atmosphere. Its units are m^2 s^{-1} and it is assumed to be constant and isotropic ($K = K_x = K_y$).

Horizontal wind velocity is allowed to vary as a function of height in the atmosphere, but is assumed to be constant within a specific atmospheric level, *l*.

$v_{l,j}$ is the terminal settling velocity, in m s^{-1}, for particles of size class, *j*, as these particles fall through a level in the atmosphere, *l*. This terminal settling velocity is a function of the particle's Reynolds number, which varies with the size of the particle as well as with atmospheric density.

Finally, Φ is the change in particle concentration at the source with time, *t*. The units of Phi are kg m^{-3} s^{-1}.

An analytical solution to the mass conservation equation is shown here.:

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

for a line plume source where x and y are position, and $x_{i,j}$ and $y_{i,j}$ are the coordinates of the center of the bivariate Gaussian distribution as shown

In this model the atmosphere is layered such that $w_{x,l}$ and $w_{y,l}$ are the true mean downwind and crosswind components of wind velocity in layer *l*; Δz_l is the thickness of layer *l*, and $v_{j,l}$ is the settling velocity for the particle size fraction *j* in layer *l*. This settling velocity depends on particle density and shape, as well as the physical properties of the atmosphere.

The parameter $\sigma_{i,j}^2$ is the variance of the Gaussian distribution, which is controlled by atmospheric diffusion and horizontal spreading of the plume. Effectively, the use of $\sigma_{i,j}^2$ lumps complex plume and atmospheric processes into a single parameter. This greatly simplifies the model, making it much easier to implement, but also ignores processes that can affect tephra dispersion such as the structure of the volcanic plume and its interaction with the atmosphere.

Once particles leave the column, the type of diffusion they experience is dependent on their size. For relatively coarse particles with relatively short particle fall-times ($t_{i,j}$), diffusion is linear and the variance is described by the equation for $\sigma_{i,j}^2$ shown here,

$$\sigma_{i,j}^2 = 2K(t_{i,j} + t_j')$$

where $t_{i,j}$ is the particle fallout time and t_j' is the horizontal diffusion time in the vertical plume. This diffusion model strongly depends on the choice of the diffusion coefficient, *K*, for large particles.

For fine particles with long settling times, a power-law diffusion model is used. Diffusion for these particles strongly depends on the particle fall time and the horizontal diffusion time of the ascending plume. These particles settle far from the volcano.

The source term of these models is an estimate of the mass per unit time released from the eruptive column at a given height.

Dispersal patterns generated by advection-diffusion models are especially sensitive to total mass of erupted material and, for proximal deposits, column height. Wind direction and velocity also have a significant effect on deposits.

The equations here make important assumptions about eruption input parameters and tephra dispersion in the atmosphere. Specifically, they suggest that, in steady wind conditions, deposits should be characterized by roughly exponential thinning downwind of the vent and a Gaussian distribution of material in the crosswind direction with a maximum along a major axis of dispersion. Far from the volcano, thinning of deposits are well described by a power law.

This concludes tutorial 4. The script for this and other tephra2 tutorials may be found under the supporting documents tab of the tephra2 online simulation tool.