Tephra2 Users Manual

Spring 2011

Tephra2 uses the advection-diffusion equation to calculate tephra accumulation at locations about a volcano based on a pre-defined set of eruptive conditions.

This manual presents background information on the tephra2 code, explains how to implement the program both through the vhub rappture gui and at the command line, and provides a number of examples which demonstrate the resourcefulness of the model.

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Background: Tephra Hazard Models

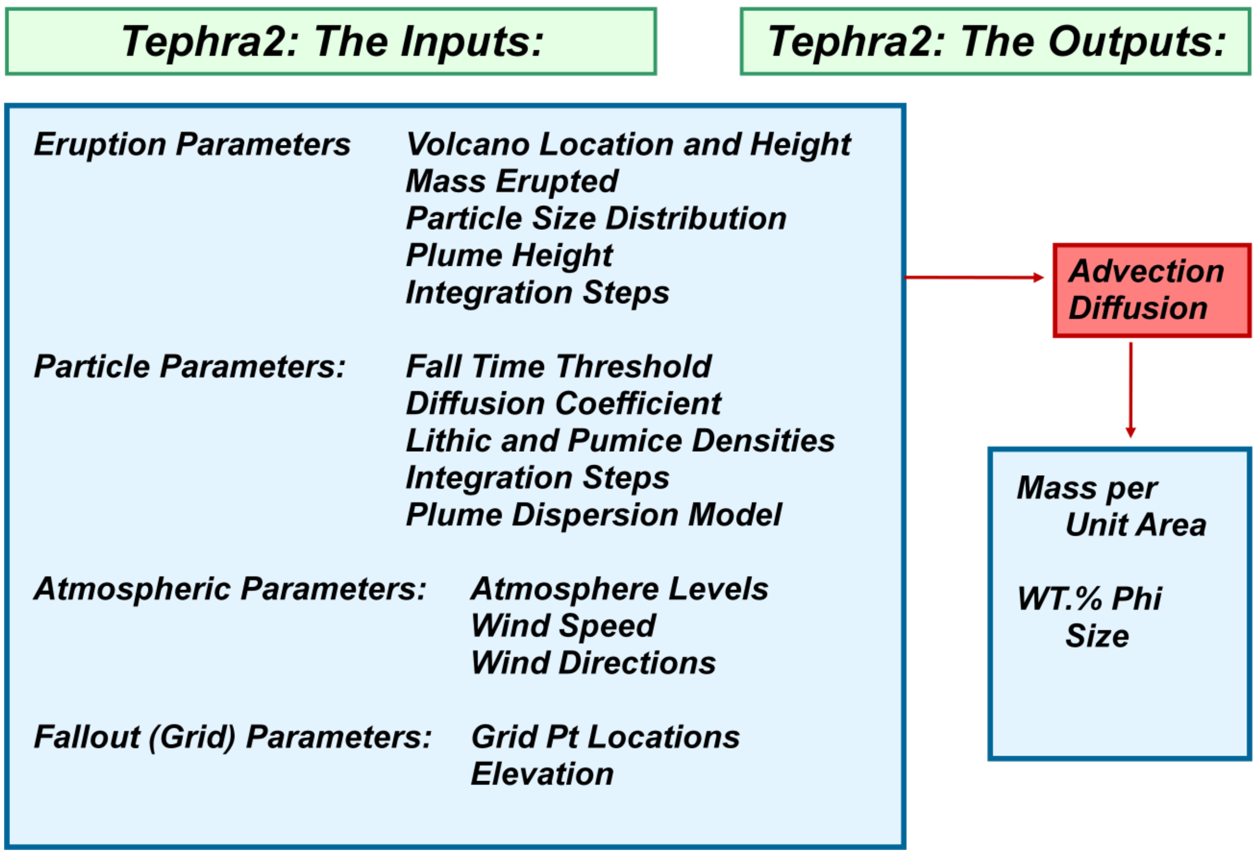
Tephra sedimentation models are used to forecast the accumulation of ejected volcanic material across a region. We need tephra fallout models that we can trust in order to make reliable forecasts crucial to hazard assessment.

Hazard Models

Numerical models used for tephra hazard assessment (Hazard Models) typically result from the combination and integration of different theories and modeling approaches depending on the specific eruptive scenario and mitigation program required. They can be grouped within two main categories: particle-tracking models and advection-diffusion models. Particle-tracking models are Eulerian or Lagrangian models that can forecast volcanic-cloud position at specific times and space. They are mainly used for aviation-safety purposes. Advection-diffusion models are Eulerian models that describe the solution of the equations of particle diffusion, transport, and sedimentation and can forecast tephra accumulation on the ground relative to a particle-release source. These models are mainly used for civil protection purposes, such as giving public warnings and planning mitigation measures.

Background: Tephra2

Inputs to the model include eruption parameters, particle parameters, atmospheric parameters, and grid parameters.



The model outputs the mass per unit area of tephra on the ground and the wt percent of each grain size at each of the supplied locations.

Uses of code output:

The mass per unit area can be used to designate hazard zones about a volcano or to make recommendations for local building practices. The wt percent of phi particles on the ground can indicate where smaller particles land which can influence respiratory health after an eruption.

In addition to the obvious implications for hazards mitigation, tephra2 can also be used as an educational tool when teaching about natural hazards, numerical modeling, and calculus applications, to name a few.

The Calculation

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:.

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

Each step in the calculation is described on the following pages and again in more detail on pages XX through XX.

Steps in the Calculation: Quick Version

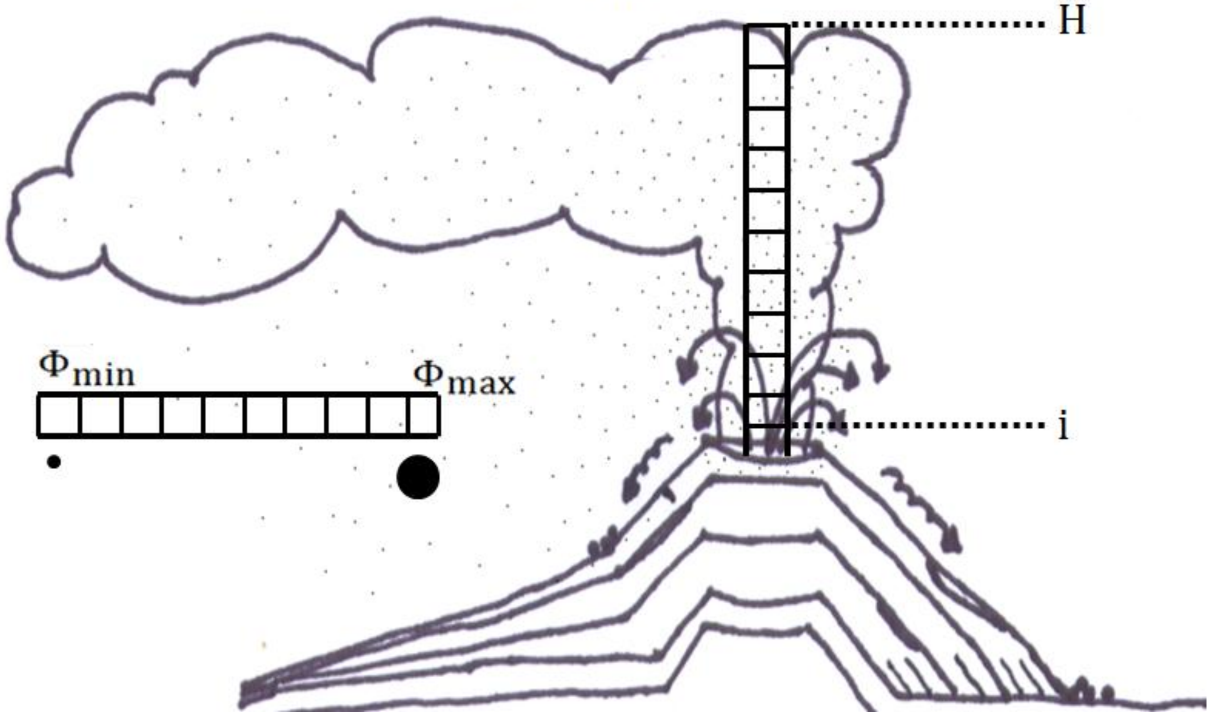
1. For each step up the eruption column (i) [vent to max column height (H)], For each particle size (j) [max ϕ to min ϕ]
2. Calculate probability of particle release at each step
3. Calculate particle fall time from a point release source
4. Modify by column diffusion
5. Modify by atmospheric diffusion
6. Fall through a layered atmosphere
7. Accumulate mass (M) at each grid location (x,y)

The Calculation

A vertical eruption column is assumed to extend above the vent.
The column is discretized and particles fall from each column height

1. For each step up the eruption column (i), from the vent to the maximum column height (H), each grain size (j) is considered:

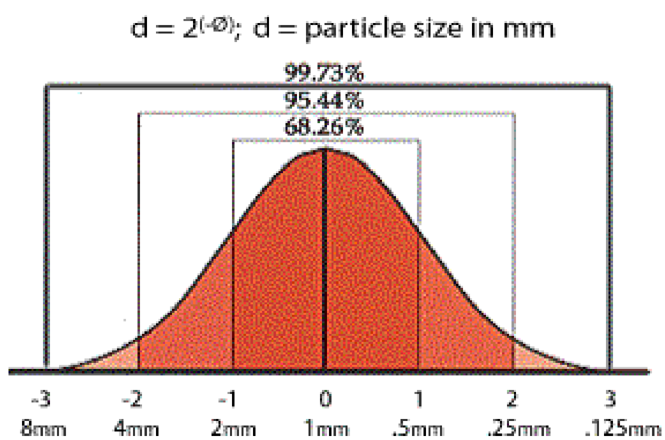
$$M(x,y) = \sum_{i=1}^{H} \sum_{j=\Phi_{\min}}^{\Phi_{\max}} M_{i,j}^{0} f_{i,j}(x,y)$$



The total grain size distribution is estimated for the eruption, assuming a normal distribution in phi units:

The grain size distribution of a deposit defines the relative amount of particles present in the deposit, sorted according to particle size.

A typical tephra deposit will have a median grain size between -1 and 1 phi (0.5 – 1.0 mm).



The Calculation

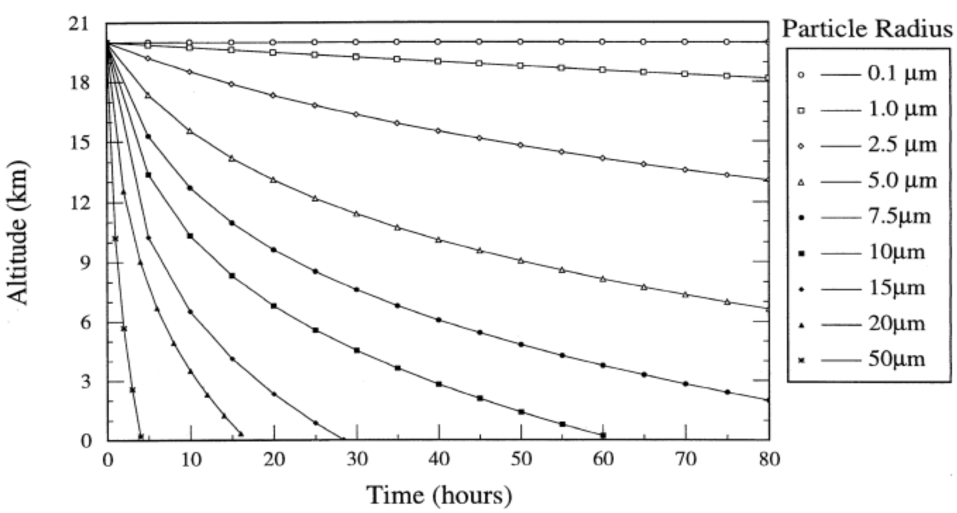
2. Calculate probability of particle release at each step. The total tephra mass is distributed vertically in the eruption column based on a probability density function for mass as a function of height. For example, for an umbrella cloud, mass might be equally distributed in the upper 20% of the total column height.

A Plinian eruption column at Lascar volcano, Chile, 1993.

3. Calculate particle fall time from a point release source. Depending on where in the column a given particle is released, it will take a calculable amount of time to fall to the ground surface.

   The particle fall time depends on particle properties (density, diameter) and atmospheric density. Gravity and air resistance help to govern the fall of particles through the atmosphere. Most particles reach a terminal velocity after a few seconds. The fall of small particles is dominated by air resistance while the fall of large particles is dominated by gravity.

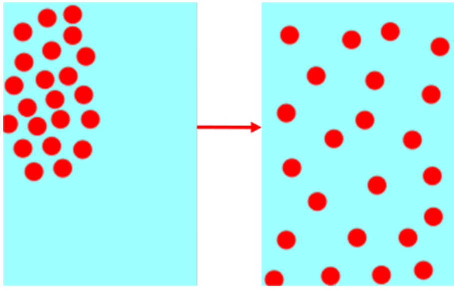
   Settling velocity is determined assuming spherical particles and accounting for the variation in particle Reynolds Number and atmospheric density.



Schneider et al., 1999, J Geophys Res 104 4037-4050

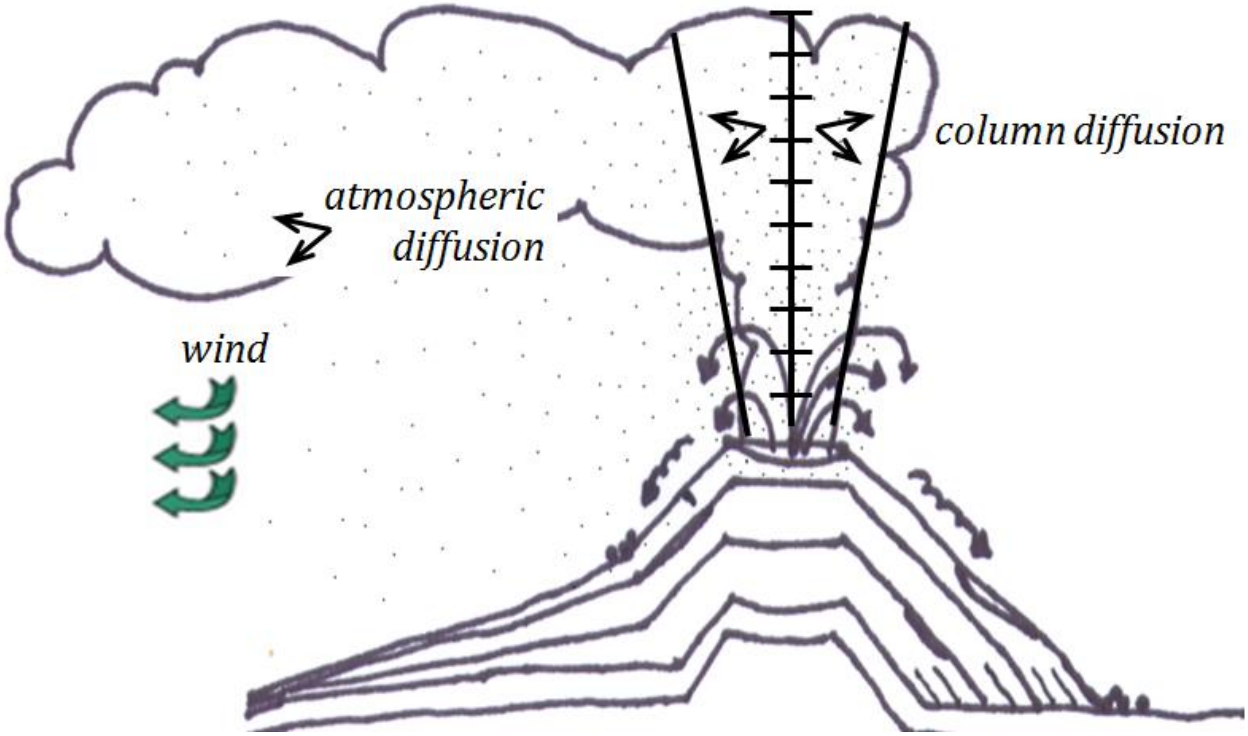
The Calculation

4. During this time, particle movement is modified by column diffusion. The eruption column radius increases with height and this affects deposition. Particles are more spread out than they would be if they were released from a vertical line source. This effect is accounted for by increasing the diffusion time as a function of height in the column.

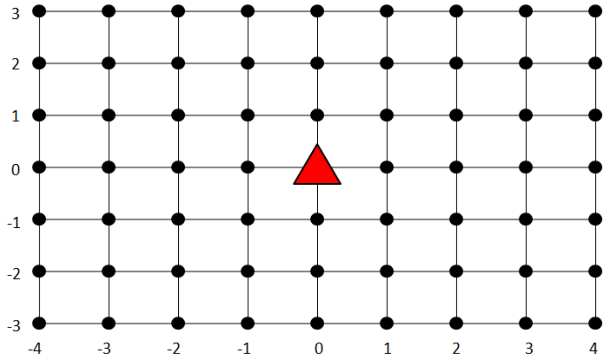


5. Particle movement is also modified by atmospheric diffusion. Diffusion of particles in the atmosphere is estimated using a bivariate Gaussian probability density function to approximate turbulence. The scale of diffusion (described by the diffusion law) depends on total particle fall time, which depends on particle size, release height, and elevation of the terrain the particle impacts.

6. Particles fall through a layered atmosphere, with layers characterized by different wind velocities.



7. In this manner, mass (M) is accumulated at each grid location (x,y).



The Calculation

Total tephra accumulation is estimated as mass per unit area; most hazard results from excessive mass loading which can lead to crop failure and roof collapse. Mass per unit area can be easily converted into thickness knowing the deposit bulk density (i.e. thickness (m) = kgm-2/density). The isomass is usually contoured over a region about the volcano.

Near Cerro Negro, 1992. Photo by C. Connor

The wt% of particles at each location can be used to identify whether or not populated areas should expect an abundance of small particulates known to cause respiratory problems in humans.

Anchorage, Alaska during an eruption of Mount Spur, 130 kilometers (80 miles) away. Photo by Richard Emanuel, USGS.

Running Tephra2: the GUI

Once you have launched the Tephra2 Tool, simply:

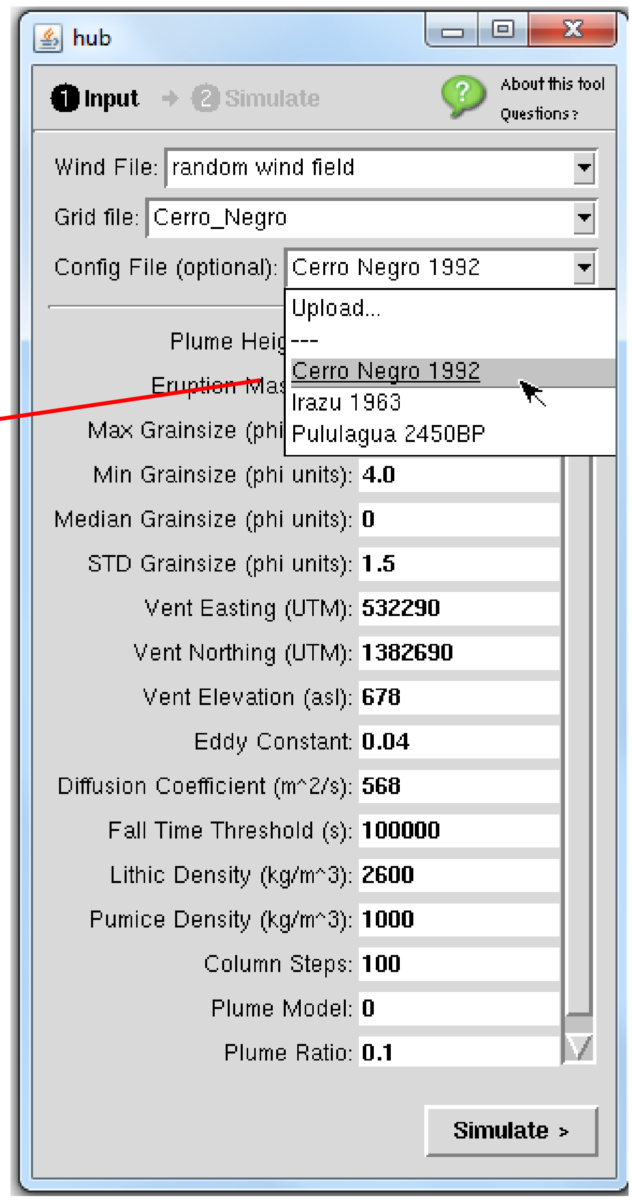
> ***Load a wind file***
> ***Load a grid file***
> ***Load a config file OR input config values into the GUI***
> ***Press 'Simulate'***

Running Tephra2 : GUI : Input

To run Tephra2 from the vhub site, launch the Tephra2 tool. In a moment, the graphical interface will appear. The first window will ask you to select your language. Once you make a selection, the tephra2 interface will appear.

To load the wind, grid, or configuration files, select an option from the drop down menu:

> Here the user can select from the pre-loaded configuration files or choose to upload a file of their own



Loading a configuration file is optional as each of the values defined in the configuration file may be defined via the graphical interface. Simply select any of the fields to change the value within.

It is important to note that the values shown will not change if one loads a configuration file from their local computer. However, the values in the loaded config file, and not those shown on the screen, will be used in the calculation.

Once all of the parameters have been specified, hit 'simulate' to run the model.

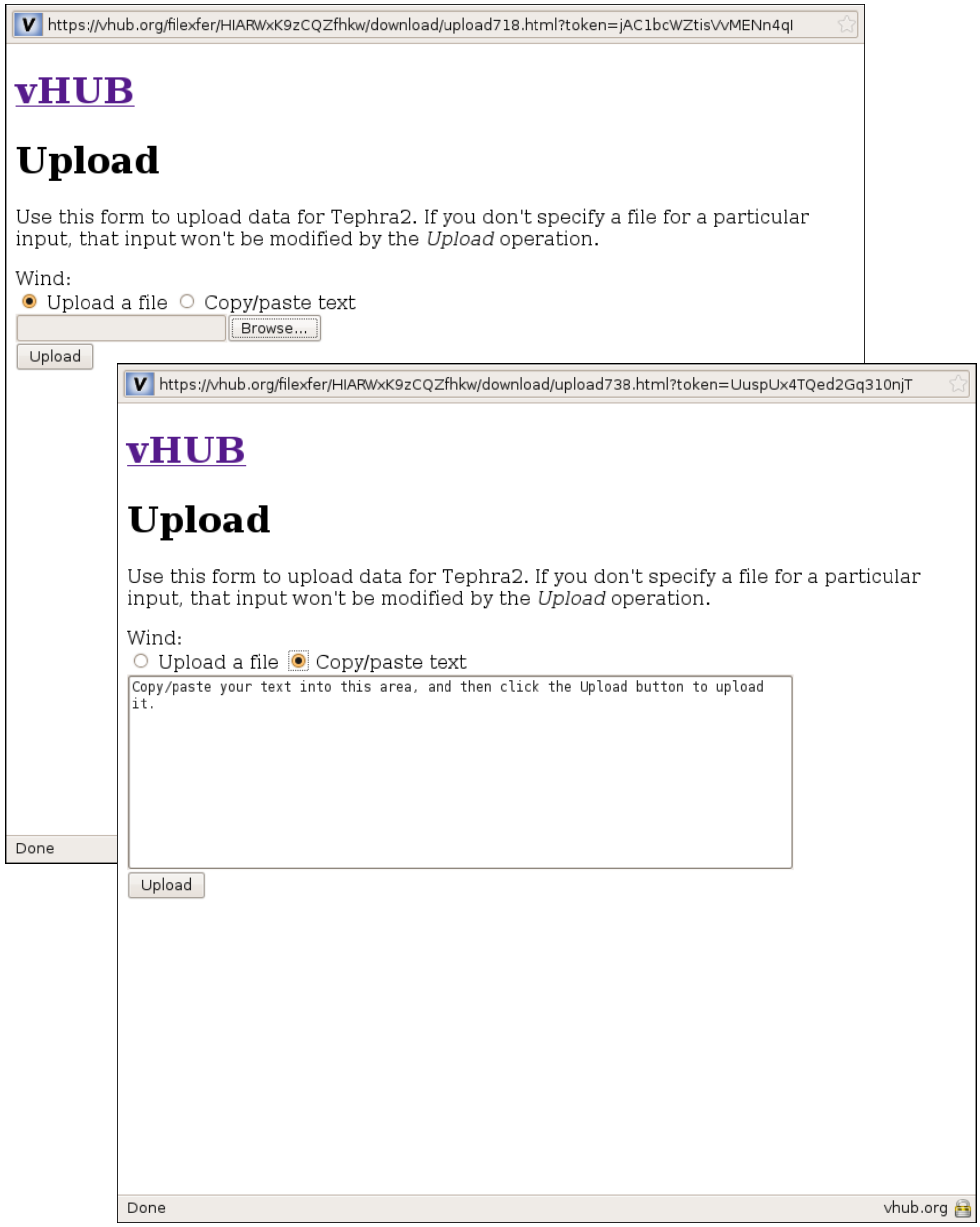
To upload a file from your home computer, select the upload option. Make sure pop-ups are enabled.

The following window will appear:

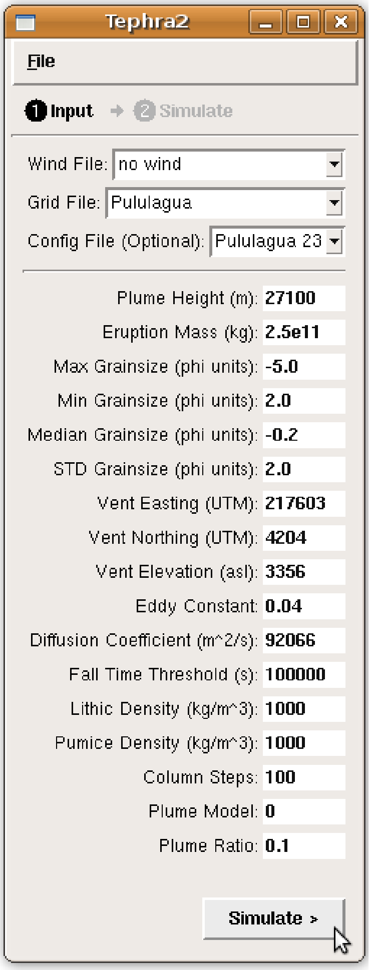
To load a file, select ‘Browse’ and indicate the file you wish to upload.

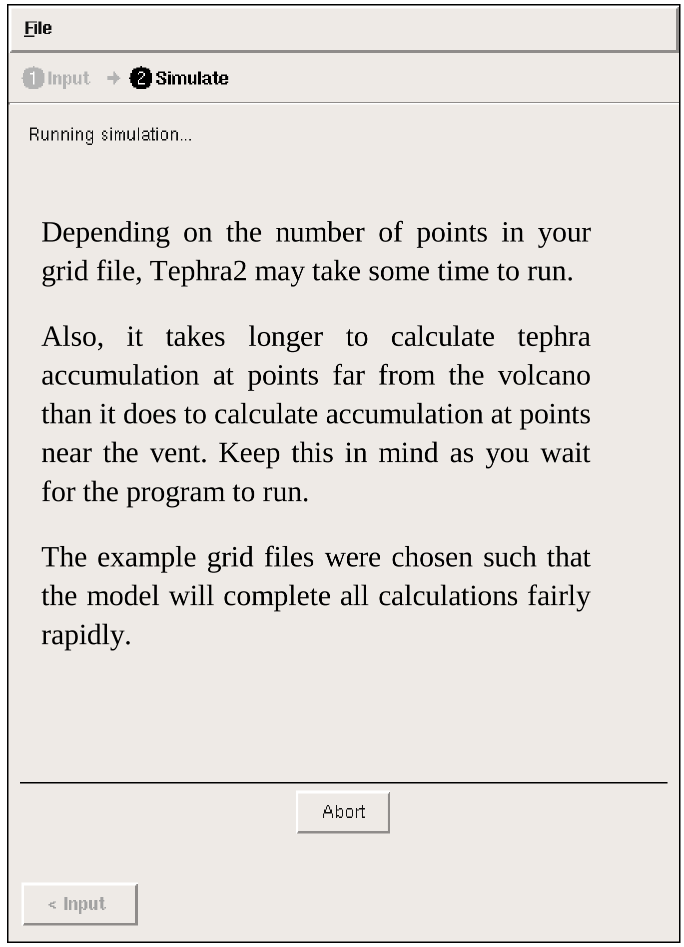
Alternatively, you may type or copy and paste information into the browser window. This option might be useful if you wish to know the amount of tephra accumulating at only one or a few points.

The necessary file format is described further XXX.



Running Tephra2 : GUI : Simulation

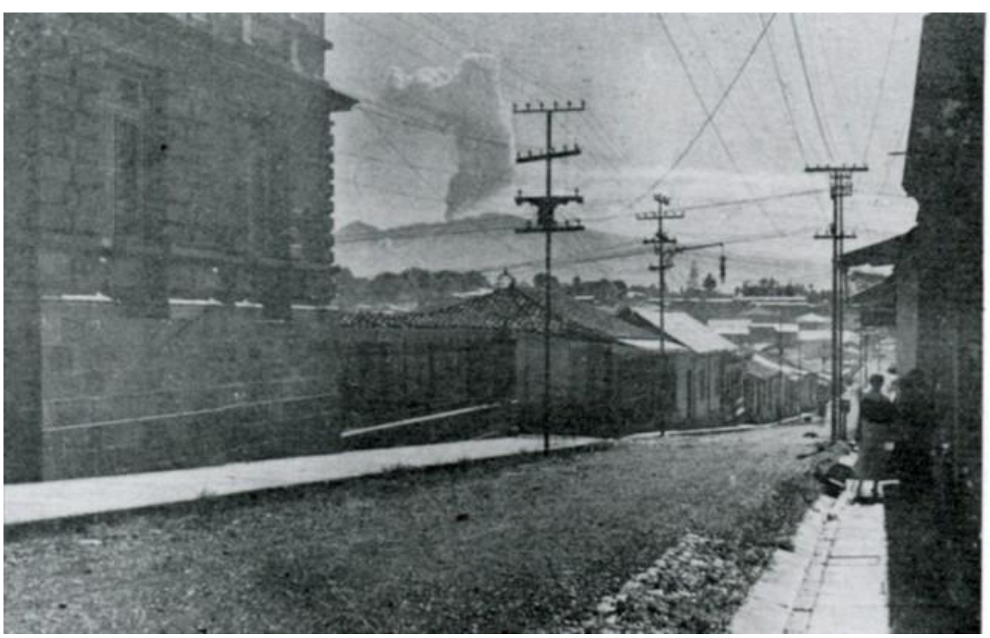




Depending on the number of points in your grid file, Tephra2 may take some time to run.

Also, it takes longer to calculate tephra accumulation at points far from the volcano than it does to calculate accumulation at points near the vent. Keep this in mind as you wait for the program to run.

The example grid files were chosen such that the model will complete all calculations fairly rapidly.



An eruption plume above the summit crater of Irazú is seen here in 1917 from the national theater in San José. All summit craters were reported to be smoking on September 27, 1917, after which activity steadily intensified.

Anonymous photo. Taken from the GVP Website:

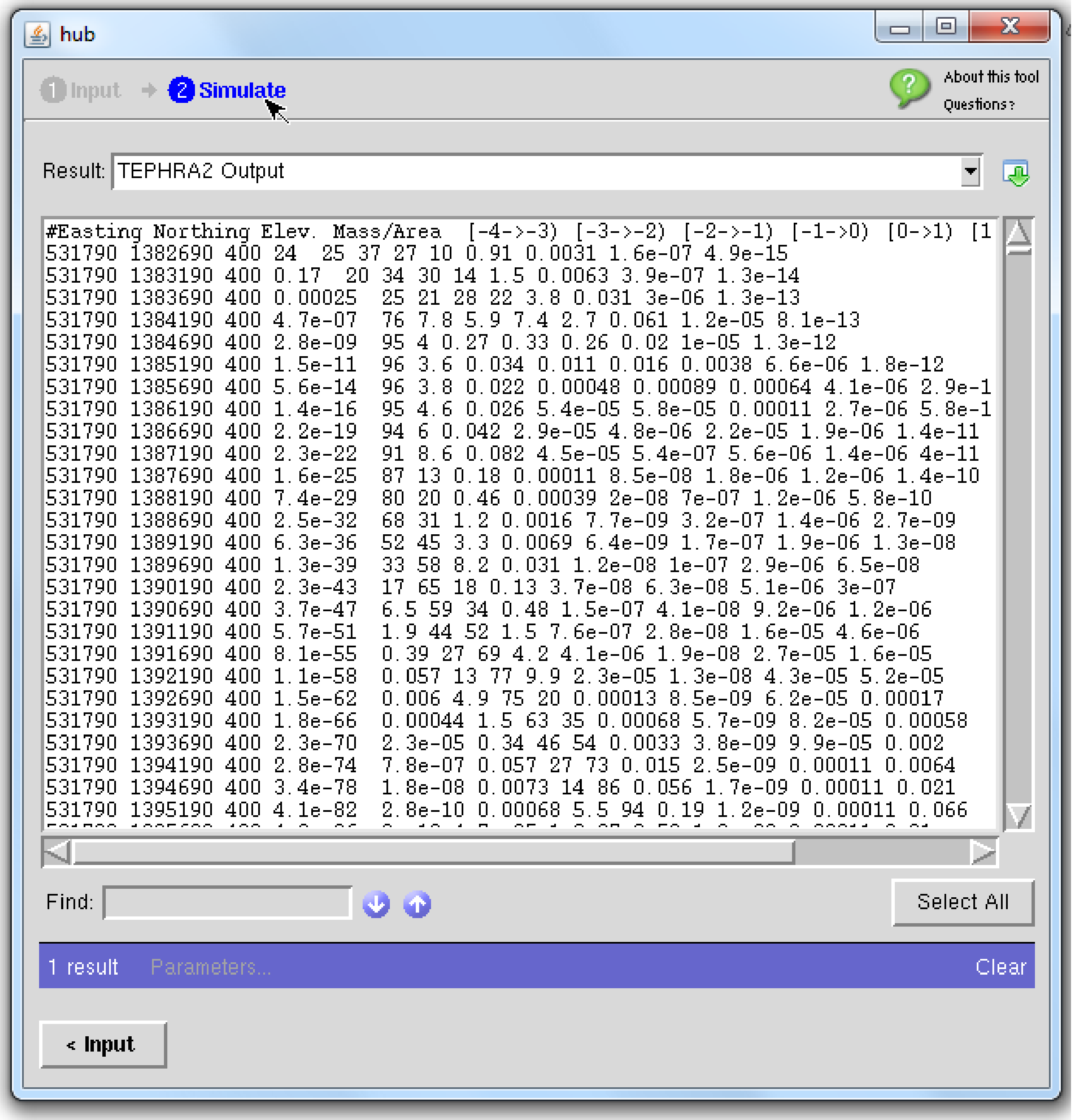
http://www.volcano.si.edu/world/volcano.cfm?vnum=1405-06=&volpage=photos

Running Tephra2 : GUI : Output

The Tephra2 GUI currently has multiple outputs, the most important of which is the numerical output of the tephra2 program, shown below.

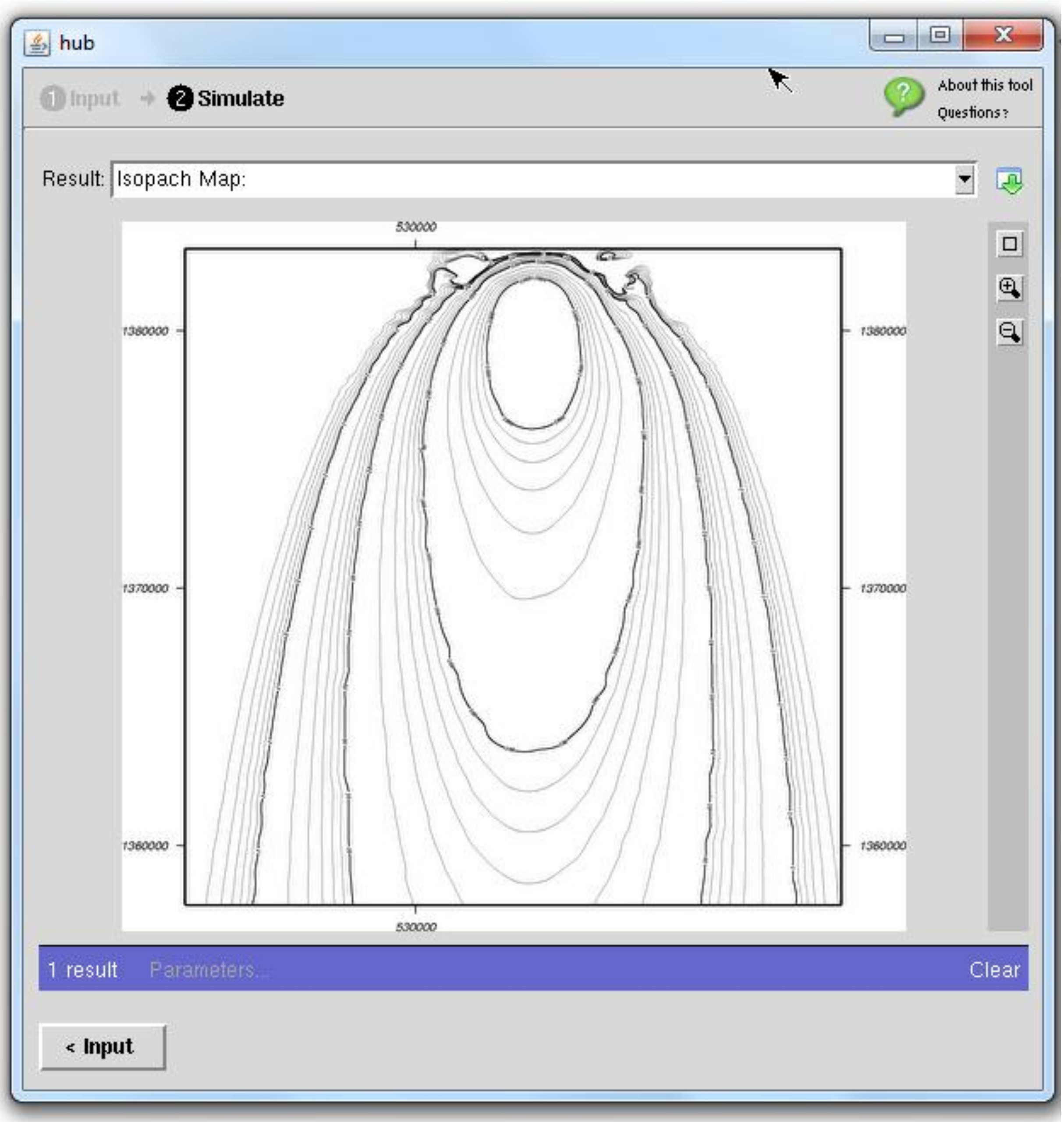
The format of the output file is:

EASTING NORTHING ELEVATION MASS WT_%_MIN_PHI WT_%_MAX_PHI



Running Tephra2 : GUI : Output

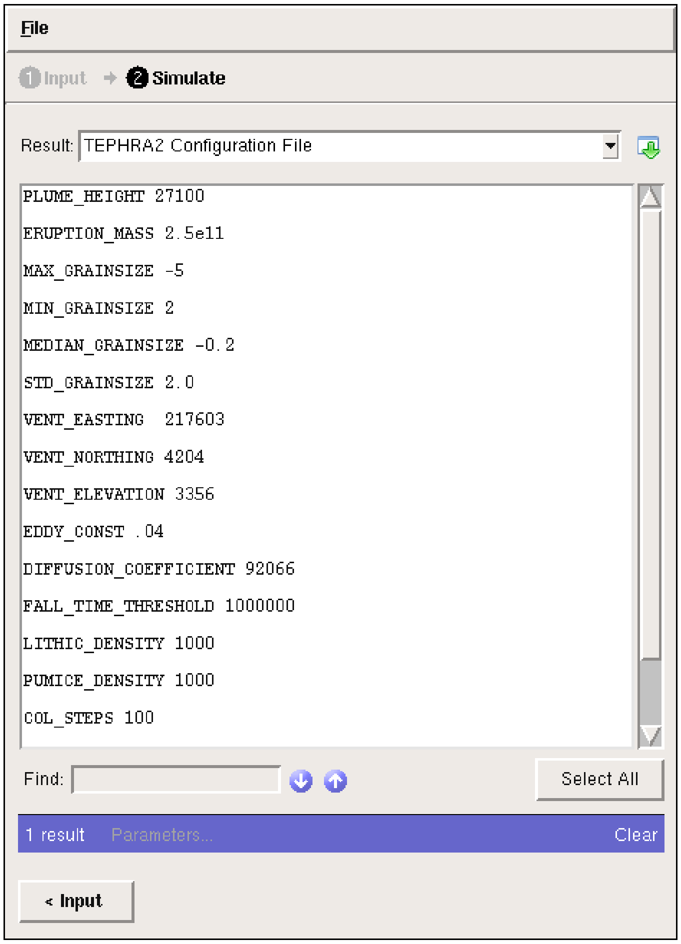
After tephra2 completes its calculations, the vhub tephra2 tool automatically contours this output to create an Isopach map. This map is available via the GUI



It is recommended that users re-create this contour plot in order to add topography or other geographical markers and to plot the most relevant isopachs on the map. To aid users in this analysis, a sample code, written in perl and utilizing GMT, is available in the supporting documents section of tephra2.

Running Tephra2 : The GUI : Output

In addition to the numerical output and Isopach map, the input configuration and wind files are also available for download via the GUI.

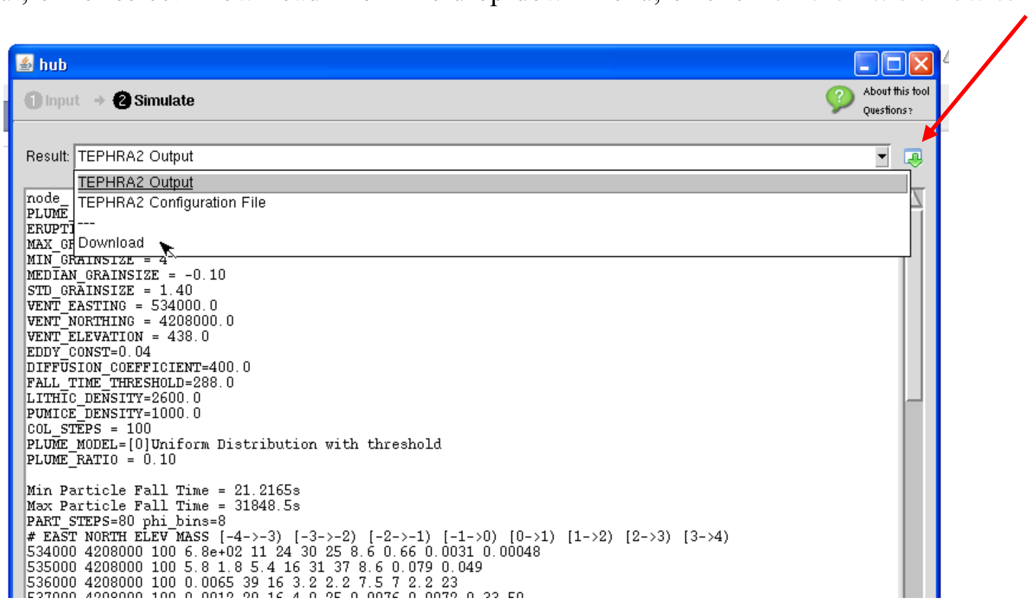


The 'Configuration File' output provides the configuration parameters in the format required by the program. This output may be saved and subsequently uploaded into the GUI for future runs. This may be useful if parameters were initially input by hand.

To return to the input screen and upload parameters for a second run, select the '< Input' button.

Note that the parameters of the previous run will be saved in the GUI.

To save the output, either select 'Download' from the drop down menu, or click on the little arrow to the right of this menu.



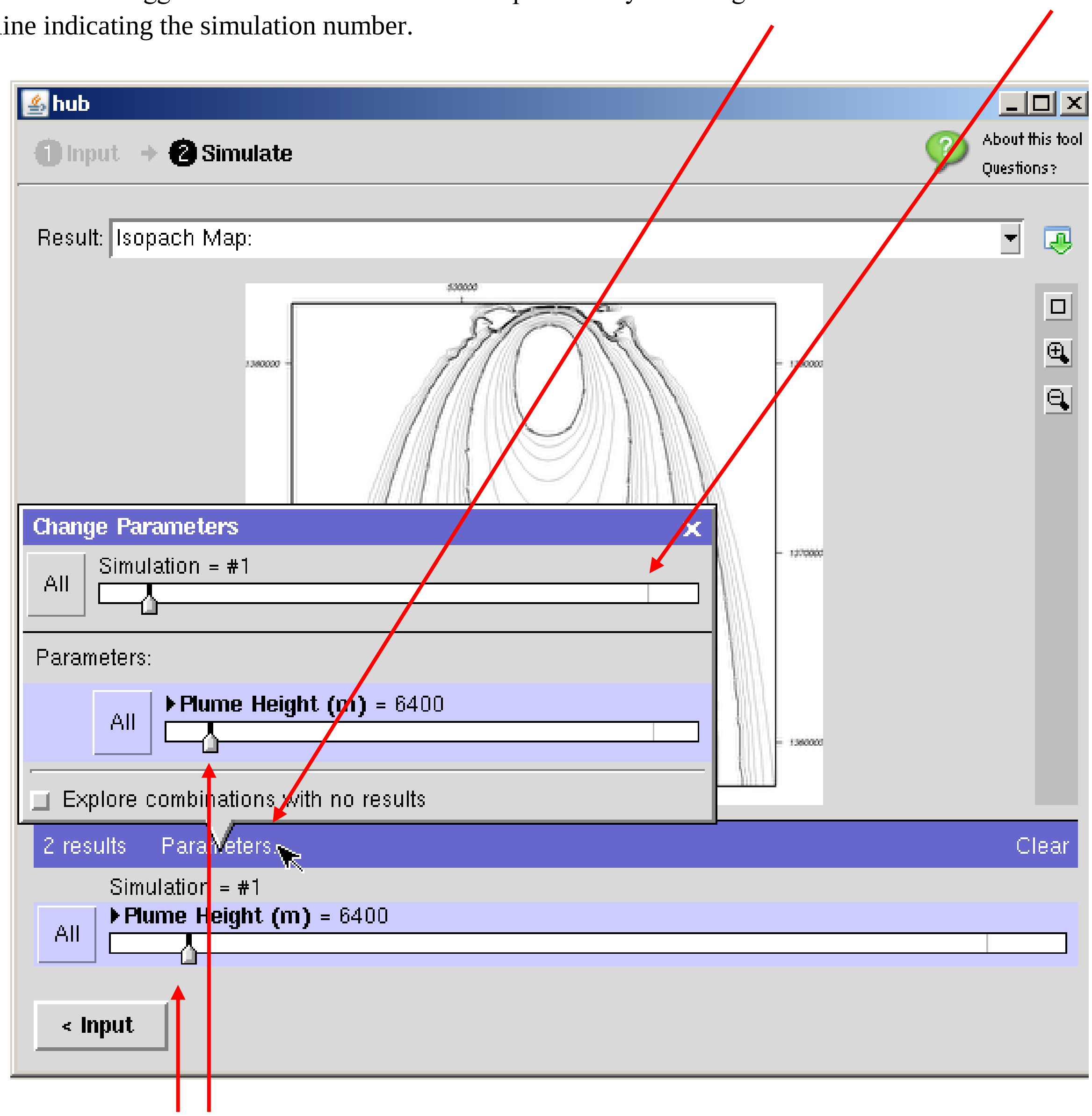
Running Tephra2: the GUI: Output

Changing the configuration file for another run:

The easiest way to change the configuration file is to open the file provided as output, type in any changes, and save the file. Simply upload the updated file into the GUI in order run the program with the revised configuration. See page XX for details on the format of this file

Another option is to input all of your configuration file information into the GUI fields, changing any parameters that need refreshing. Run the GUI to determine results. To change a parameter at this point, return to the input screen and make the necessary changes.

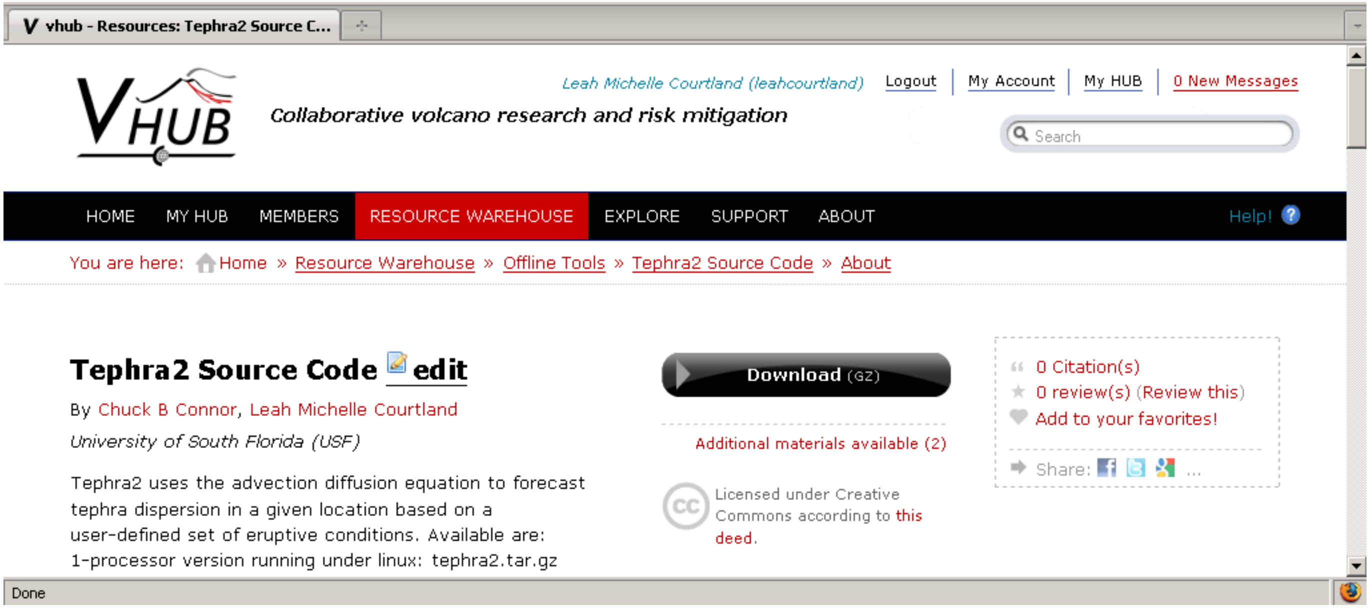
It is possible to toggle between the results of multiple runs by selecting 'Parameters. . .' and then clicking on the grey line indicating the simulation number.



Indicates that the parameter 'Plume Height' was changed between simulations 1 & 2.

Downloading Tephra2 Source Code

The Tephra2 source code is provided as a separate tool located in the offline tools section of the hub.



To install tephra2, first unzip the file and then run the make file in the tephra2 directory to build the executable. Next place your three input files (a configuration file, a wind file, and a grid file) into the same directory as the executable. To run the program, simply type ./tephra2 config.file grid.file wind.file > tephra2_output.txt tephra2 will run and the output will be stored in the current directory.

If you wish to use the graphical user interface, you will still need to download the tephra2 source code from the offline simulation tools as I just described. In addition, you must download the complete Tephra2 tool by selecting the download link directly below the launch button. This will download tephra2 itself as well as the graphical user interface. In order to run the graphical user interface on your home computer it will be necessary to install rappture, and in order for the Isopach map to be automatically generated you must have both gmt and proj installed. Additionally, you will need to alter some scripts in order to use the tephra2 gui from a personal computer. Build the version of tephra2 that is available from the offline tools, and then copy and paste it into the rappture directory inside the tephra2 folder that you downloaded from the tephra2 online simulation tool.

Next you will need to edit the t2wrap.pl script as follows:

At line 6, replace XXX with the path to the examples directory. For example:

/home/leah/Vhub/tephra2cout/examples

Comment out line 7

At line 124, add a “./” and a “>Tephra2out.dat” be sure to use this exact filename

at line 130, delete $rapdir/

comment out line 131

at line 178 delete $rapdir/

You may also want to consider commenting out line 190 in order to automatically save the tephra2 output

Once you have made these changes to the t2wrap.pl script, you should be able to launch the tephra2 gui by typing rappture into the command line from within the rappture folder.

Running Tephra2: Command Line

Once Tephra2 has been downloaded and installed, simply type the following into the command line:

```
./tephra2  config.file  grid.file  wind.file  >  tephra2_output.txt
```

Running Tephra 2: Command Line: Input

TEPHRA2 requires three input files: a configuration file, a grid file, and a wind file.

Running Tephra 2: Command Line: Input

Configuration File

The configuration file is a text file consisting of KEY-NAME VALUE pairs, one pair per line, separated by a space. The KEY-NAME must not be changed. Only the VALUE should be changed by the user.

The KEY-NAMES for the configuration files are as follows:

CONFIGURATION FILE:

PLUME_HEIGHT	Maximum height of tephra column (meters above sea level)
ERUPTION_MASS	Total mass of tephra erupted from the volcano (kg)
MAX_GRAINSIZE	Maximum particle size of tephra erupted from the volcano (phi units) Note: Suggested limit: -6 phi. Larger particles land very near the vent where Tephra sedimentation models are known to fail.
MIN_GRAINSIZE	Minimum particle size of tephra erupted from the volcano (phi units) Note: suggested limit: 6 phi. Smaller particle experience agglutination, and other complicated processes not modeled by tephra2.
MEDIAN_GRAINSIZE	Median particle size erupted from the volcano (phi units)
STD_GRAINSIZE	Standard deviation of particle size of tephra erupted from the volcano (phi units)
VENT_EASTING	Easting location of vent (UTM coordinates)
VENT_NORTHING	Northing location of vent (UTM coordinates)
VENT_ELEVATION	Elevation of vent (UTM coordinates)
EDDY_CONST	Describes atmospheric diffusion (Fickian diffusion parameter, Earth value = 0.04)
DIFFUSION_COEFFICIENT	Term describing the advection and diffusion of particles through the atmosphere As this term accounts for multiple processes, values range from ~100 – 10,000
FALL_TIME_THRESHOLD	Fall time at which diffusion model changes from linear to power law diffusion
LITHIC_DENSITY	Density of small particles ejected from the vent (kg m^{-3})
PUMICE_DENSITY	Density of large particles ejected from the vent (kg m^{-3})
COL_STEPS	Number of steps into which to discretize the eruption column. Suggested value: 100
PLUME_MODEL	Describes the diffusion of particles in the eruption column based on mass A value of 0 corresponds to a well-mixed plume; 1 to a Suzuki distribution
PLUME_RATIO	Describes where in the column the majority of mass resides A value of 0 corresponds to mass released from every height A value of 0.9 corresponds to mass released from the upper 1% of the column

Running Tephra 2: Command Line: Input

Wind File:

The wind file is a text file consisting of three values per line separated by a space. Wind direction refers to the direction the wind is blowing toward.

The format of the wind file is: Height (m) Windspeed (m/s) Direction (+/- degrees)

EXAMPLE WIND FILE:

94	4.2	201.0
708	3.6	199.4
1364	4.1	195.8
2829	5.4	169.3
3953	6.9	144.5
5244	7.8	120.8
6760	8.5	110.6
8643	4.9	122.4
9834	1.7	203.6
11318	3.4	253.1
13252	6.9	245.3
16020	8.1	252.0
18469	8.2	252.2
20795	6.8	252.1
24349	5.4	276.3
27199	3.6	294.4
32143	4.6	278.8

Grid File

The grid file is a text file consisting of three values per line, values separated by a space. These 3-tuples are determined by the user and represent locations around the volcano where mass per unit area values of tephra are calculated by the program. Easting and Northing are specified in meters (usually UTM coordinates with respect to a particular zone) and the elevation is specified as meters above sea level.

The format of the DEM file is: Easting (m) Northing (m) Elevation (m)

EXAMPLE GRID FILE

645304	2158285	1000
645904	2158285	1000
646604	2158285	1000
647404	2158285	1000
648304	2158285	1000
649304	2158285	1000
650404	2158285	1000
. . .		

For best results, the elevation should be equal for all points on the grid. Once the calculation is complete, output may be draped over topography if desired.

Running Tephra 2: Command Line: Output

Tephra2 outputs the mass per unit area at each grid location and the associated weight percent of each phi size at each grid location specified in the input grid file. The range of phi sizes is specified in the input configuration file.

The format of the output file is:

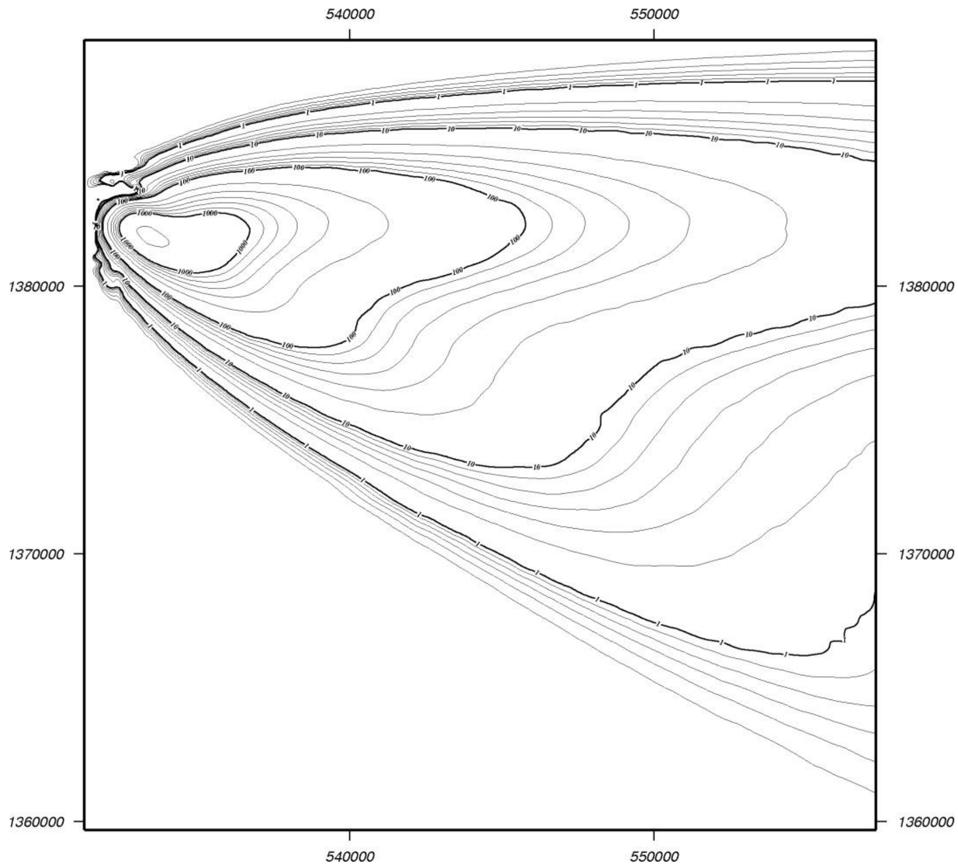
EASTING NORTHING ELEVATION MASS WT_%_MIN_PHI WT_%_MAX_PHI

EXAMPLE OUTPUT FILE

```
531790 1382690 400 8.8  17 30 31 19 3.4 0.074 0.00012 1.8e-09
531790 1383190 400 0.77  29 27 24 17 3.7 0.098 0.00018 2.9e-09
531790 1383690 400 0.1  58 31 7.1 2.9 0.91 0.043 0.00012 2.5e-09
531790 1384190 400 0.025  55 37 7.5 0.81 0.053 0.0058 3e-05 9.7e-10
531790 1384690 400 0.0045  45 42 11 1.6 0.0062 0.00058 7e-06 4e-10
531790 1385190 400 0.0006  33 46 18 3.8 0.016 4.8e-05 1.5e-06 1.8e-10
```

This output is only automatically contoured if tephra2 is executed via the GUI. A perl script to contour the data is included in the supporting documents of the tephra2 tool. With this, one can choose the most appropriate isopachs to plot.

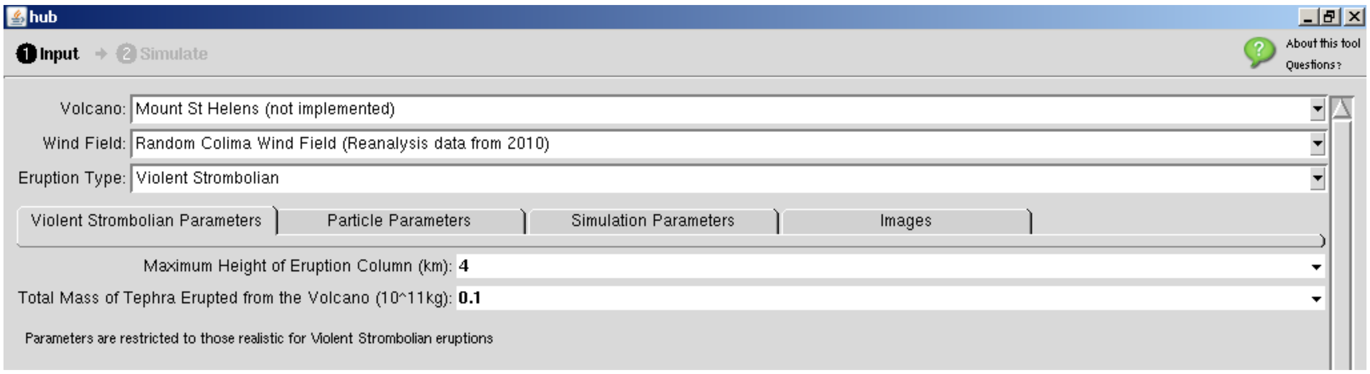
The contour plot may be draped over topography using GMT or other mapping software.



Tephra2: Education Mode

There is another version of tephra2 that was designed specifically for student use. The user interface for this mode is quite different from the standard interface, though both versions execute identical source code. It is available under as an online simulation tool.

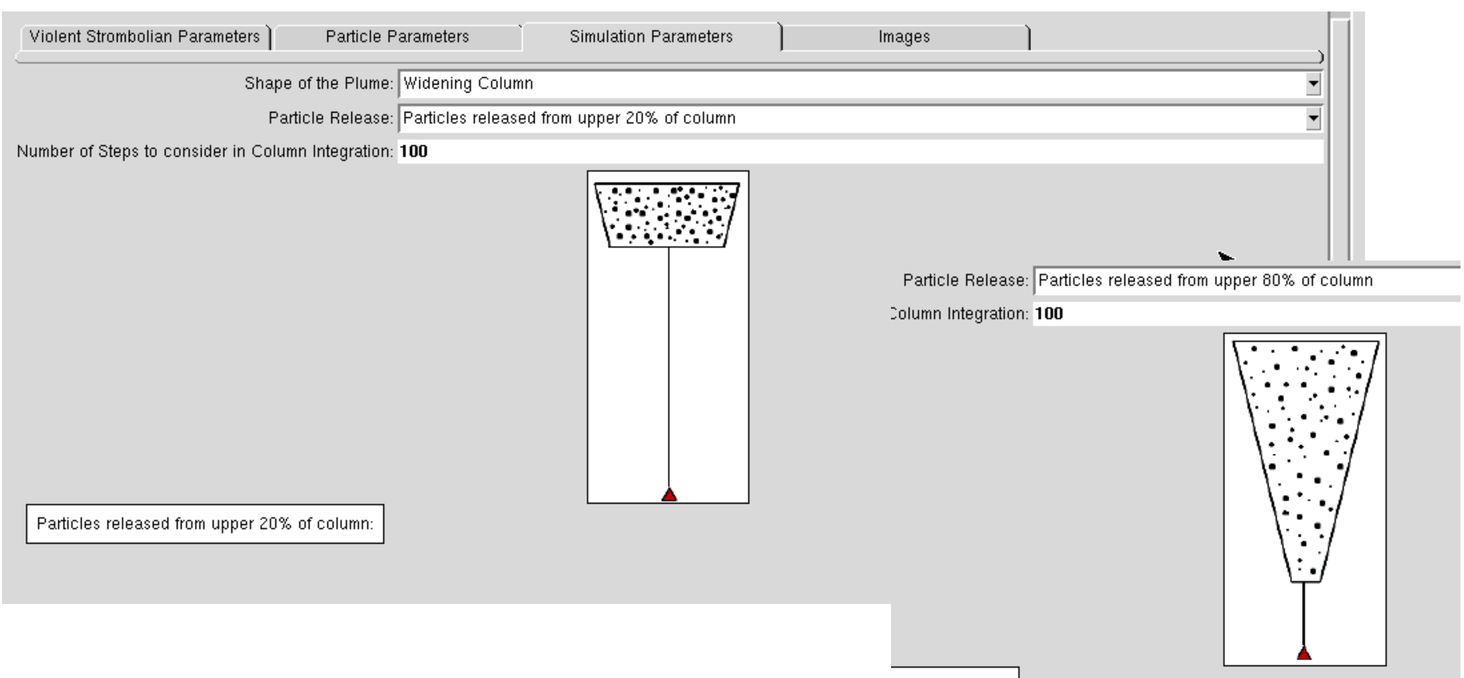
In the educational version, users do not have the option of uploading their own data and must instead select from the list of volcanoes provided.



Users also must choose between a number of pre-set wind fields. These include a few constant wind files that may be executed again and again, as well as the option to choose randomly from approximately 150 wind fields gathered from reanalysis data near Colima volcano over the course of a year.

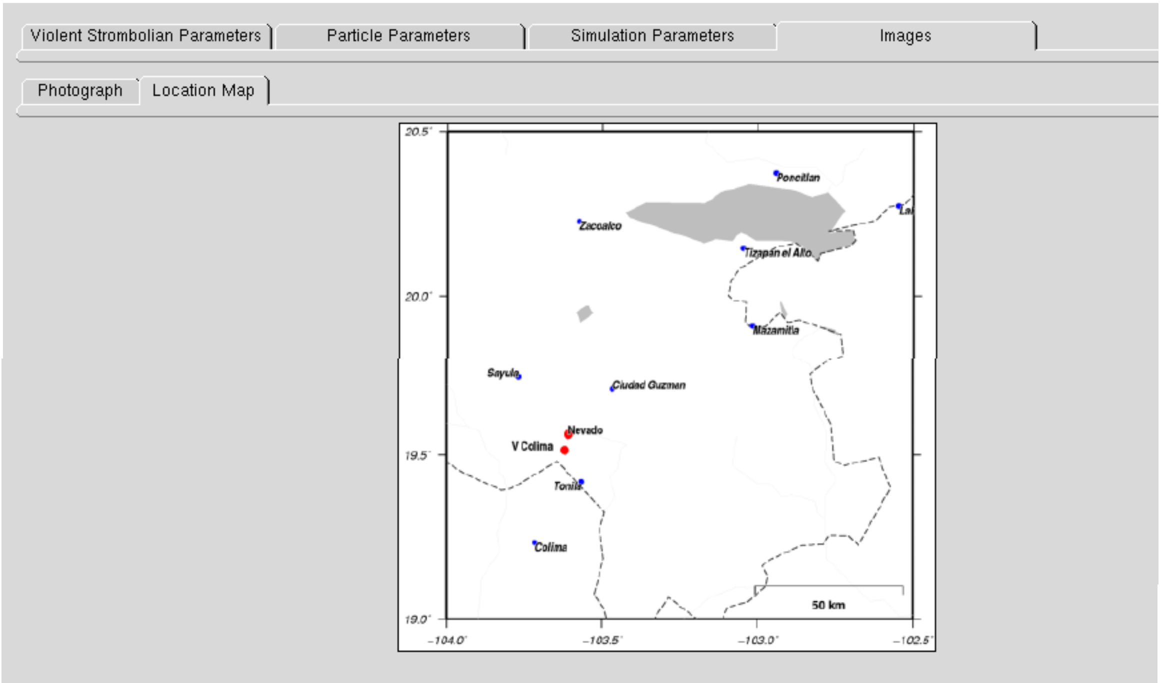
The next critical selection is the eruption type. Users can specify violent strombolian, subplinian, plinian, or ultraplinian eruption. Users are then able to vary parameters like column height and total mass erupted, but only within the limits that are realistic for the eruption type selected.

Under the Simulation Parameters tab, users can select the shape of the plume and the location from which particles are released. An image depicts where in the column particle are released. Changing the Particle Release field will cause change this image so that students can envision how this option effects the eruption they will simulate.

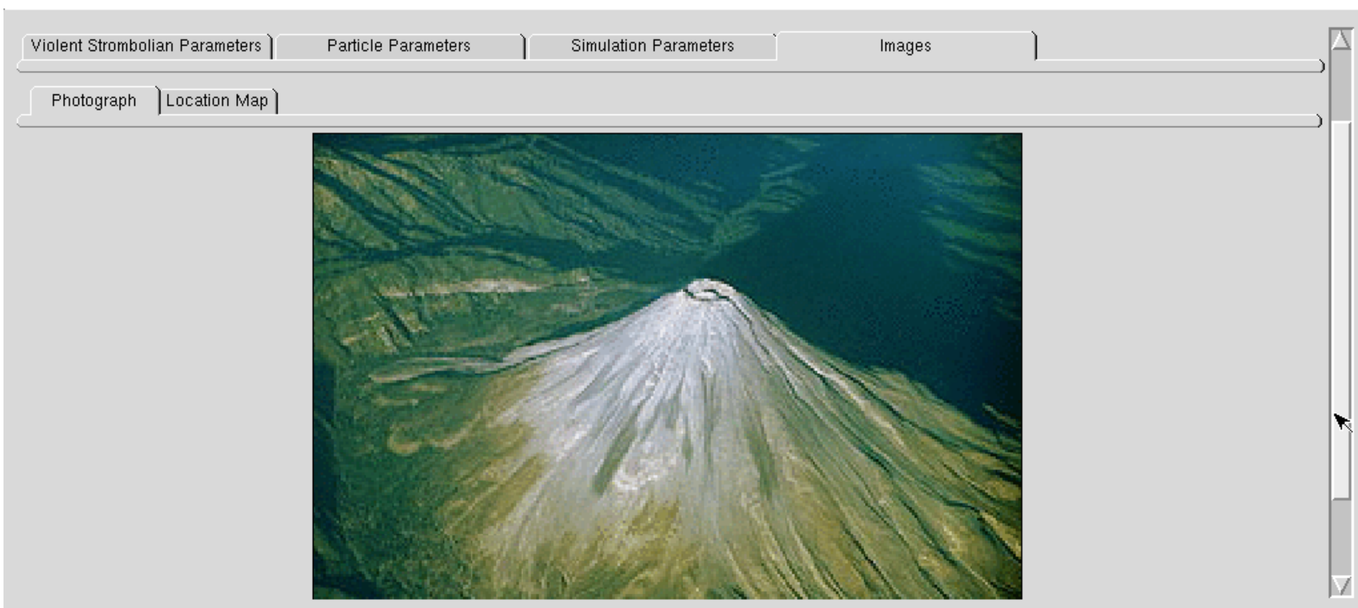


Tephra2: Education Mode

Under the images tab students can view a basic location map in order to orient themselves and begin to think about the volcanoes proximity to population centers and major watersheds.

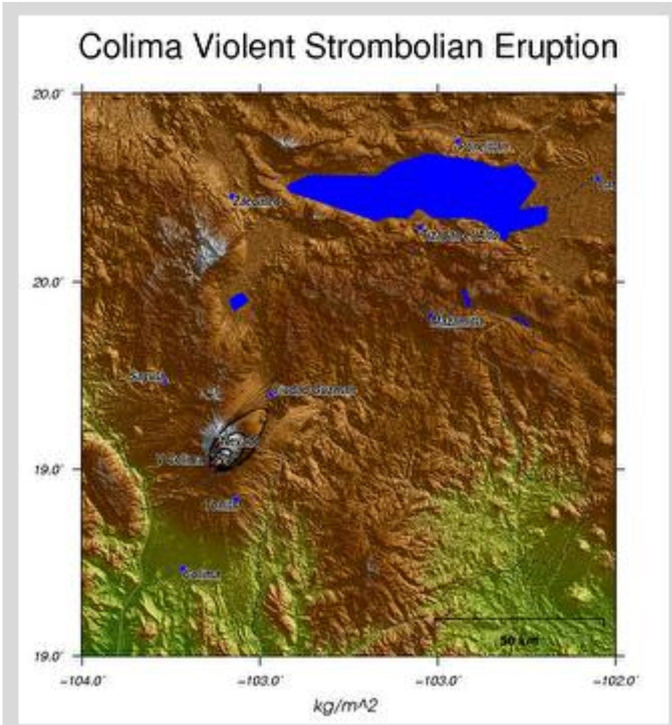


Also included is a photograph of the volcano.

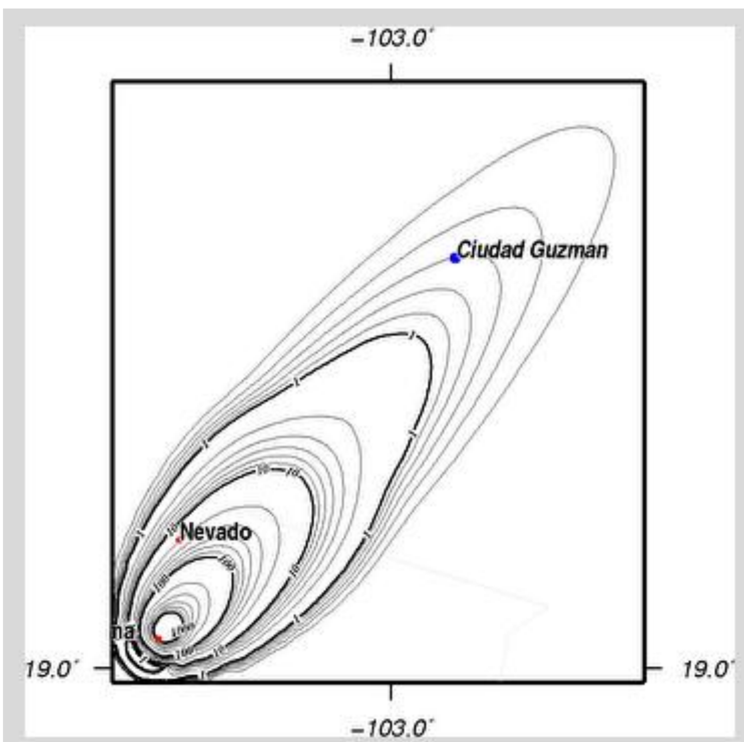


A number of parameters are not visible in this mode and instead have been preset behind the scenes. These include: grainsize standard deviation, eddy constant, diffusion coefficient, and column steps. The values of all of these parameters are available by selecting the input file from the output menu of the GUI.

Additionally, the Isopach map generated in this mode is overlain over a location map which includes cities and topography. This is possible because the locations were pre-determined.



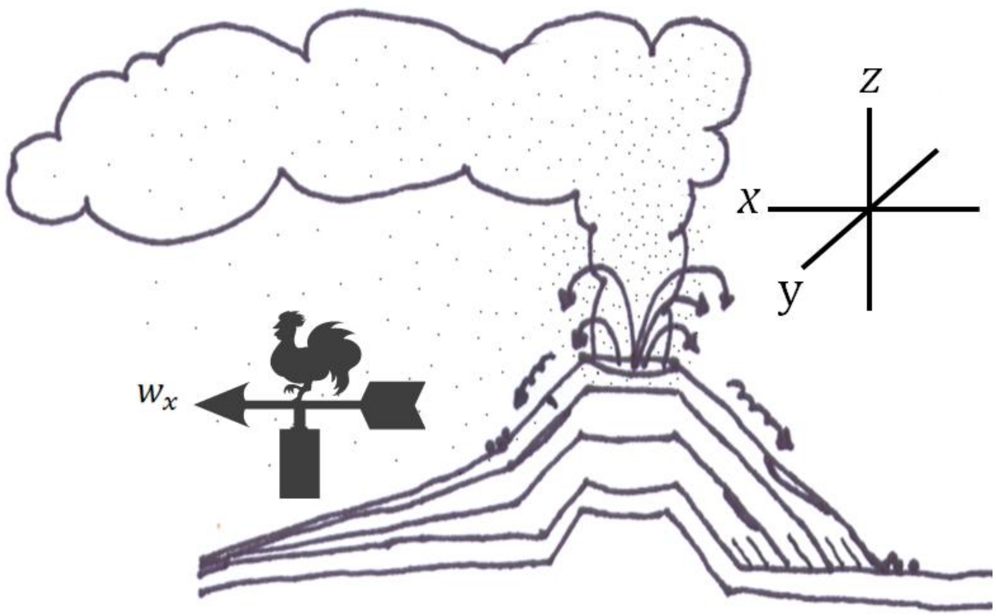
Additionally, a map without the topography which is instead sized to the isopachs is also available.



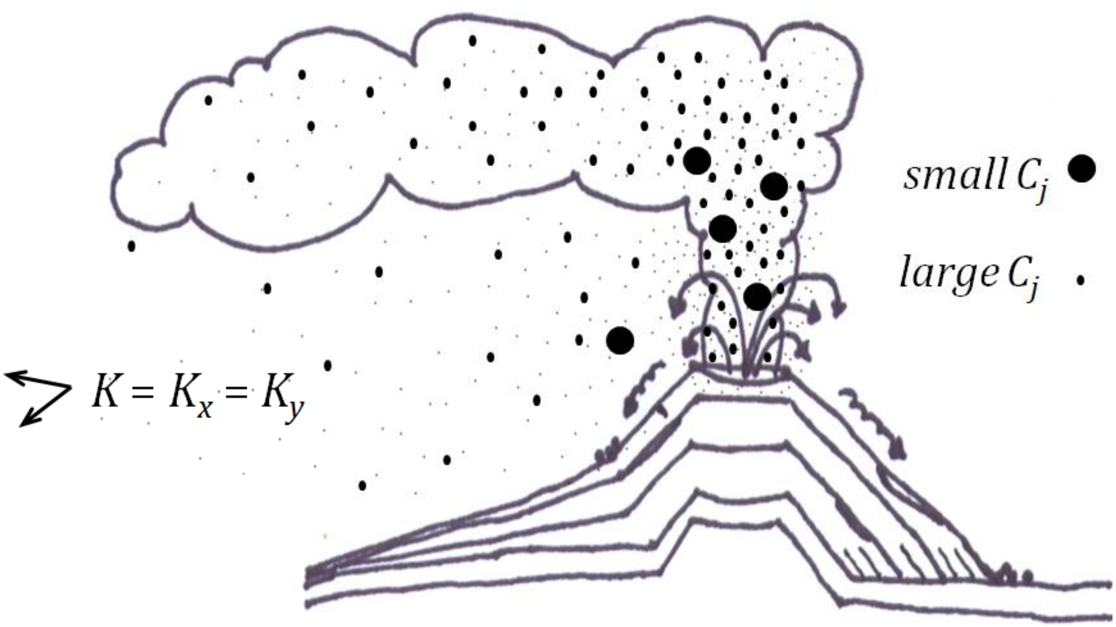
The Calculation: The Details

The numerical simulation of tephra accumulation can be expressed by a simplified mass-conservation equation of the type [Suzuki., 1983]:

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



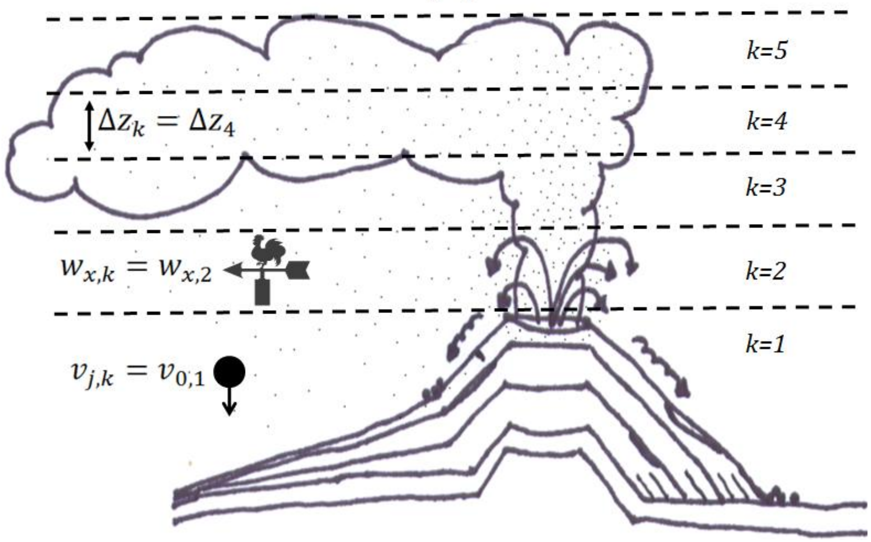
where, x is positive in the mean downwind direction, y is the mean cross-wind direction, and z is vertical; C_j is the mass concentration of particles (kg m^{-3}) of a given particle size class, j; w_x and w_y are the x and y components of the wind velocity (m s^{-1}) and vertical wind velocity is assumed to be negligible; K is a horizontal diffusion coefficient for tephra in the atmosphere (m^2 s^{-1}) and is assumed to be constant and isotropic ($K = K_x = K_y$); [continued on next page]



The Calculation: The Details

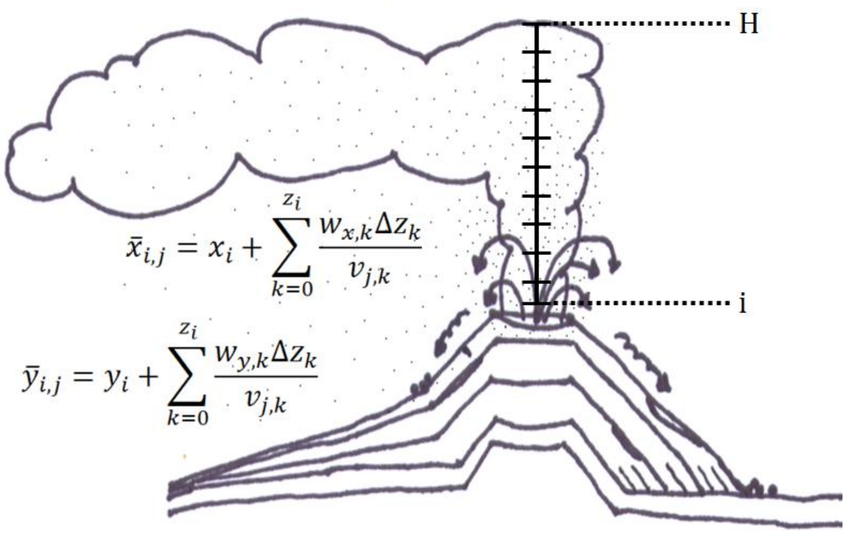
In this model the atmosphere is layered such that w_x and w_y are true mean downwind and crosswind components of wind velocity in layer k. Horizontal wind velocity is allowed to vary as a function of height in the atmosphere, but is assumed to be constant within a specific atmospheric level. .Δz_k is the thickness of layer k, and $v_{j,k}$ is the settling velocity. The terminal settling velocity is calculated for each particle size, j, released from a height in the eruption column, i, as a function of the particle's Reynolds number, which varies with atmospheric density [Bonadonna et al., 1998]. This settling velocity depends on particle density, shape, and physical properties of the atmosphere. Φ is the change in particle concentration at the source with time, t (kg m^{-3} s^{-1}).

$$\bar{x}_{i,j} = x_i + \sum_{k=0}^{z_i} \frac{w_{x,k} \Delta z_k}{v_{j,k}}$$



An analytical solution to the mass conservation equation can be written as:

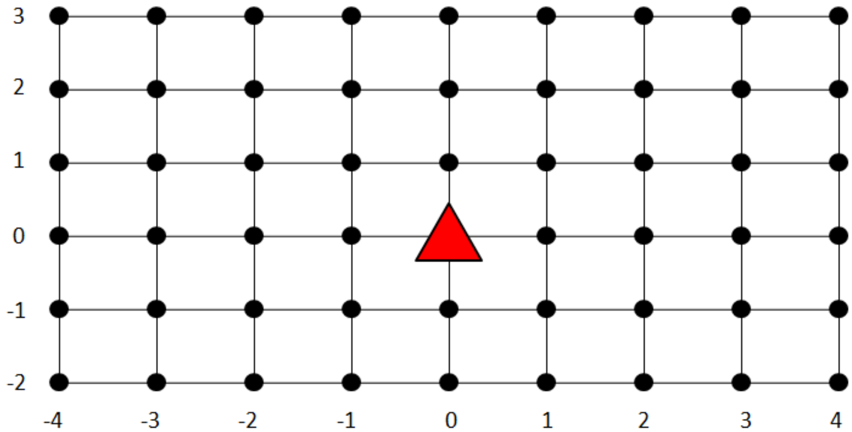
$$f_{i,j}(x,y) = \frac{1}{2\pi\sigma_{i,j}^2} \exp\left(-\frac{\left(x - \bar{x}_{i,j}\right)^2 + \left(y - \bar{y}_{i,j}\right)^2}{2\sigma_{i,j}^2} \right)$$



for a line plume source where $\bar{x}_{i,j}$ and $\bar{y}_{i,j}$ are the coordinates of the center of the bivariate Gaussian distribution.

The Calculation: The Details

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



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

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 [Suzuki, 1983]. 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.

The source term of these models is an estimate of the mass per unit time released from the eruptive column at a given height. 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 (Fick's law) and the variance is described by [Suzuki, 1983]:

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

Where 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 [Bonadonna, 1998]. Diffusion for these particles strongly depends on the particle fall time and the horizontal diffusion time of the ascending plume [Suzuki, 1983]. These particles settle far from the volcano.

Ultimately, particles leaving the plume sink through the atmosphere to the ground. Dispersal patterns generated by advection-diffusion models are especially sensitive to total mass of erupted material and, for proximal deposits, column height [Scollo et al., 2009]. Wind direction and velocity also have a significant effect on deposits.

Model Verification and Validation

Verification

TEPHRA2 is a highly modular code. Each function has been tested for correct computation. An additional test to verify the function of the code has been to compare the output mass – by integrating the isomass source of the tephra deposit – with the input mass specified in the configuration file. These two masses should agree.

We find that the masses always agree within 1 percent, usually within 0.1 percent, as long as several conditions are met. These are: (1) the grid file covers sufficient area to contain the entire deposit (usually we perform tests in which the 99.99% of the deposit falls within the grid area), (2) the grid spacing is sufficiently dense so that the near-vent mass is well-defined by the output grid (this usually means that the test must be performed with a sufficiently dispersive column), (3) the isomass falls on to a “flat” digital elevation model (DEM).

Validation

The predecessor to TEPHRA2, TEPHRA, was validated by comparing output from the code to actual eruptions by modeling deposits. The details of this validation are found in the papers:

Connor, L.J., and C.B. Connor, 2006, Inversion is the solution 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 Simona, Tarantola Stefano, Bonadonna Costanza, Coltelli Mauro, Saltelli

Andrea, Sensitivity analysis and uncertainty estimation for tephra dispersal models, in press in JGR.

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.

TEPHRA2 is currently in the process of being validated. The geometry of deposits predicted by tephra2 is in good agreement with the geometry of deposits at Cerro Negro Volcano, Nicaragua. (Kruse et al., submitted to Bull Volc. 2011) Additional comparisons are necessary in order to fully validate the model.

Notable Simplifying Assumptions

Particle Size Distribution

Evidence has shown that some volcanic deposits display a bimodal rather than Gaussian distribution of particle sizes. However, almost without fail these distributions are characterized by a single dominant peak and a much smaller secondary maximum. Though distributions are technically bimodal, the dominant peak is well fit by a Gaussian distribution, substantiating the use of such a distribution in the model. Here the assumption is allowed because it appears to be approximate reality well.

Near-Vent Processes

The fact that Tephra2 does not attempt to account for near-vent processes is a strong indication that the model will fail to accurately predict tephra accumulation in these areas. Models which fail to take into account processes known to have a significant effect on a system will be unable to fully characterize the system. Comparison of model results to the deposits of actual eruptions has borne this out: current versions of tephra sedimentation models have been found to drastically under-predict tephra accumulation in the near-vent region. This indicates that other forces are at work in this local. Here the assumption defines the locations where the model is likely to be accurate and where to expect the model result to diverge from reality.Someone unfamiliar with the simplifying assumption might organize the construction of buildings or other public spaces in dangerous locations based on the under-prediction of the hazard in these areas.

Well-Mixed Plume

The Tephra2 model assumes that particles of every size are well-mixed throughout the entire plume. This assumption is unlikely to be an accurate portrayal of plume dynamics. Instead, it is more likely that larger particles fall out of the plume at lower elevations with the smallest particulates lofted to the greatest heights. The assumption is made in order to simplify the mathematics. Additionally, no one is exactly sure how tephra is actually distributed in the plume, and so it may be premature to enforce any more complicated distribution. The fact that the code has been found to accurately display the distribution of tephra on the ground suggests that the majority of a volcanic deposits is likely not overly sensitive to the mass distribution of tephra in the column. The fact that the model compares well with actual deposits, rather than its physical correctness, legitimizes the assumption in this case. We continue to utilize the model even though the underlying assumption is likely incorrect because the model result has been legitimized by observations.

Layered Atmosphere

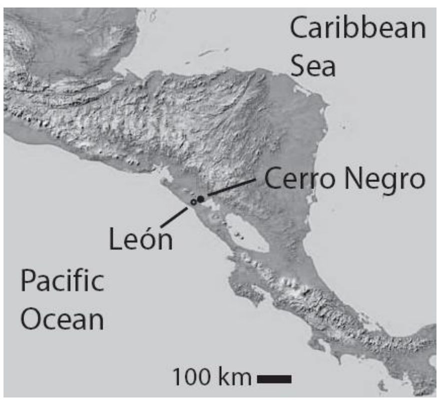
Tephra2 divides the atmosphere into horizontal layers within which wind speed and direction are constant but between which they are allowed to vary. The real atmosphere is instead comprised of eddies, updrafts, and downdrafts, all of which change position over time. Despite this, the approximation of the atmosphere as static and of constant value within any horizontal plane simplifies the model and works well for small eruptions that do not spread out over large areas or continue for long periods of time. In the case of larger eruptions or those which occur in highly variable wind conditions, this atmospheric model is likely a poor representation of reality and in these cases the Tephra2 model would not be expected to provide an accurate prediction of the mass loading of tephra on the ground

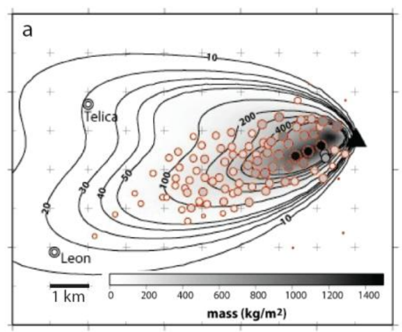
Example Eruption: Cerro Negro, 1992

Example included in GUI

Cerro Negro is a small basaltic cinder cone within the Central American volcanic arc that formed in 1850 and has erupted approximately 24 times since. Eruptions typically last hours to days and are characterized by columns extending 4 − 8 km into the atmosphere. Tephra falls from numerous Cerro Negro eruptions have impacted local residents and the population center in León, Nicaragua, ~30 km west-southwest of the vent. Steady trade winds tend to advect tephra towards the WSW.

Cerro Negro erupted in 1992 after 21 years of quiescence. The 7 km eruption column was observed by the Instituto Nicaragüense de Estudio Territoriales (INETER). The activity was accompanied by dramatic widening of the vent and erosion of the cinder cone. The 1992 eruption consisted of two phases. The initial phase, lasting approximately 7 hours, was characterized by an energetic plume reaching approximately 7 km into the atmosphere. The second phase, lasting approximately 17 hours, was characterized by a weak, bent over plume of column height 1 – 4 km [Connor et al., 1993].





Isopach map created by inverting trench data with Tephra2 (inversion edition)

Photos by C. Connor

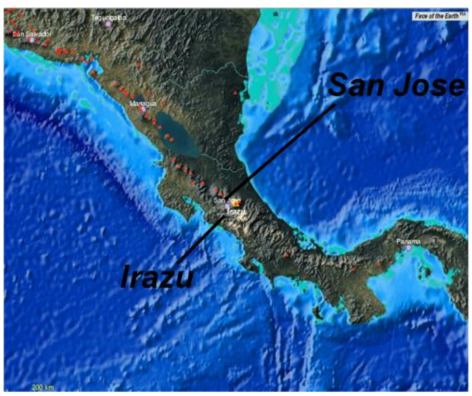
Example Eruption: Irazu, 1963

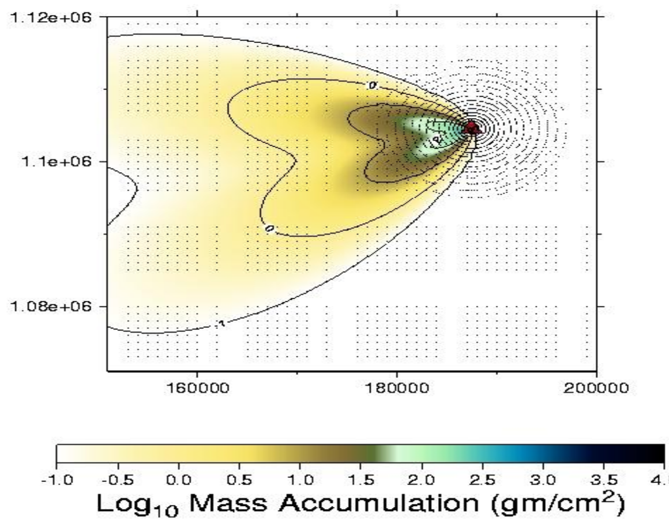
Example included in GUI

Irazu Volcano, located in Cost Rica, is recognized as one of the largest and most active volcanoes in South America. The volcano has several active craters, the largest of which delves 900 feet (275 m) into the edifice. Eruptions here typically range in explosivity from VEI 1 – 3.

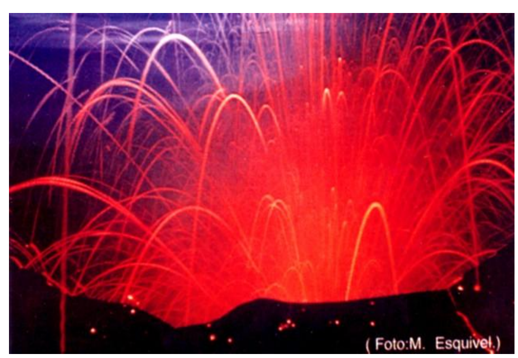
Ash fall from the 1963-65 eruption of Irazú affected both populated areas and agricultural lands. In the weeks following the beginning of the eruption on March 13, 1963 dense ash fall at times restricted visibility to 30 m in the capital city of San José, paralyzing traffic. Ash fall caused extensive damage to farmlands, and about 2000 dairy cows either died of disease and malnutrition or had to be killed. Remobilization of the heavy ash blanket during the rainy season caused mudflows that destroyed houses, roads, and bridges, and caused fatalities. [information taken from GVP Website].

GUI data taken from





Isopach map created by gridding Tephra2 output



Pics obtained from GVP website

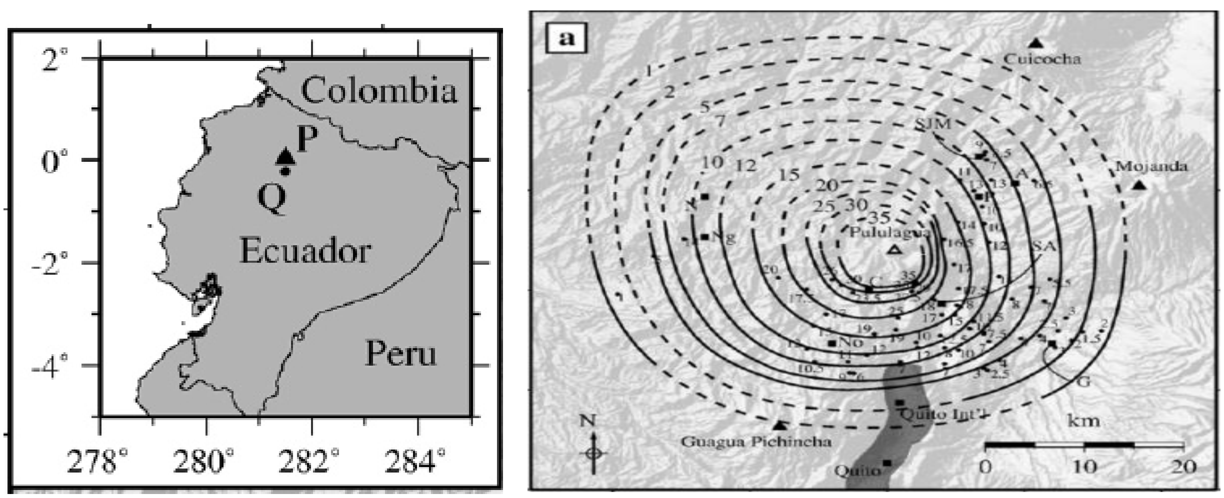
Example Eruption: Pululagua, 2350 BP

Example included in GUI

Pululagua is a relatively low, forested volcano immediately north of the equator, about 15 km north of Quito. The volcano contains a 5-km-wide summit caldera narrowly breached to the west and partially filled by a group of dacitic lava domes. Older pre-caldera lava domes are found on the eastern, SE, and southern sides of the caldera, with a group of younger pre-caldera lava domes primarily on the eastern side. Four post-caldera domes rises up to 480 m above the caldera floor. Large explosive eruptions producing pyroclastic flows took place during the late Pleistocene and Holocene. Caldera formation took place during a series of eruptions lasting 150-200 years beginning about 2650 radiocarbon years ago. The latest dated eruption occurred from post-caldera lava domes about 1670 years ago and produced lava flows and pyroclastic flows. The GUI example models one fallout later, data from Volenkik, 2010.

Information from GVP Website: http://www.volcano.si.edu/world/volcano.cfm?vnum=1502-011

Photos taken from GVP Website



Isopach map created by inverting trench data with Tephra2 (inversion edition)

Additional Reading:

Suzuki's (1983) model computes the mass of tephra deposited at a location relative to the eruption source using an analytic solution to the diffusion - advection equation and a line source for tephra in the eruption column. A complete description of the original mathematical development is available in:

Suzuki, T., 1983. A theoretical model for dispersion of tephra, in: D. Shimozuru and I. Yokoyama (eds) Arc Volcanism: Physics and Tectonics, Terra Scientific Publishing, Tokyo, 95-116.

The model used here is slightly modified. See:

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

Bonadonna, C., C.B. Connor, B.F. Houghton, L. Connor, M. Byrne, A. Laing, and T. Hincks, 2005. Probabilistic modeling of tephra dispersion: hazard assessment of a multi-phase eruption at Tarawera, New Zealand, Journal of Geophysical Research, 110 (B03203).

Further Reading:

Barberi, F., G. Macedonio, M.T. Pareschi, and R. Santacroce, 1990. Mapping the tephra fallout risk: an example from Vesuvius, Italy, Nature, 344, 142-144.

Costa, A., G. Macedonio and A. Folch, 2006. A three-dimensional Eulerian model for transport and deposition of volcanic ashes, Earth and Planetary Science Letters, 241 (3-4), 634-647.

D'Amours, R., 1998. Modeling the ETEX plume dispersion with the Canadian emergency response model, Atmospheric Environment, 32 (24), 4335-4341.

Heffter, J.L., and B.J.B. Stunder, 1993. Volcanic Ash Forecast Transport and Dispersion (Vaftad) Model, Weather and Forecasting, 8 (4), 533-541.

Hurst, A.W., and R. Turner, 1999. Performance of the program ASHFALL for forecasting ashfall during the 1995 and 1996 eruptions of Ruapehu volcano, New Zealand Journal of Geology and Geophysics, 42 (4), 615-622.

Macedonio, G., M.T. Pareschi, and R. Santacroce, 1998. A numerical simulation of the Plinian fall phase of 79 AD eruption of Vesuvius, Journal of Geophysical Research-Solid Earth and Planets, 93 (B12), 14817-14827.

Volentik A.C.M., Bonadonna C., Connor C.B., Connor L.J., and Rosi M. Modeling tephra dispersal in absence of wind: insights from the climactic phase of the 2450 BP Plinian eruption of Pululagua volcano (Ecuador). Journal of Volcanology and Geothermal Research, 193(1-2), pp. 117-136, doi:10.1016/j.jvolgeores.2010.03.011