SOFTWARE VALIDATION TEST PLAN AND REPORT FOR THE VOLCANIC ASH DISPERSAL AND DEPOSITION CODE TEPHRA, Version 1.0

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Prepared by

R. Janetzke
R. Benke
D. Hooper

Center for Nuclear Waste Regulatory Analyses
San Antonio, Texas

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Approved by:

Philippe Dubreuilh, Manager
Geology and Geophysics

4/29/2008
Date

ABSTRACT

During a violent strombolian eruption, volcanic material is ejected and dispersed according to such factors as the height of the eruption column, particle-size distribution, and structure of the winds aloft. Volcanic ejecta, comprising a mixture of ash, cinders, bombs, and blocks, are collectively referred to as tephra. If radioactive waste was entrained in the conduit of a potential volcanic event, tephra and waste could be transported in the resulting eruption plume. By employing parallel computer processing, the computer code TEPHRA allows the user to calculate expected tephra (ash) and any entrapped uranium (fuel) accumulation at specified points on a spatial grid, thus simulating a three-dimensional initial deposit by sedimentation out of the volcanic plume. Various components of the model are based on empirical relationships and data from observed and monitored violent strombolian eruptions. TEPHRA code incorporates the effects of the wind field on atmospheric transport and subsequent deposition of tephra and fuel. This document describes tests executed to perform sensitivity analyses and parametric studies of input parameters for the TEPHRA code. TEPHRA output is also compared to field measurements for the December 1995 Cerro Negro eruption in Nicaragua.

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1 SCOPE OF VALIDATION

The TEPHRA code allows the user to calculate the probability distribution of the amount of volcanic tephra (ash) and any entrapped uranium (fuel) accumulation due to a potential volcanic event. The TEPHRA code, which employs parallel computer processing, is based on the theoretical models presented in Suzuki (1983) and Jarzemba, et al. (1997) with additional formulations presented in Bonadonna, et al. (2005).

This document describes 16 tests executed to perform sensitivity studies of the most important input parameters. Five parameters were not studied, because they were either not used in the code (due to their association with legacy features of the code) or were of minimal significance to the operation of the code (initial ejecta velocity, standard deviation of ash particle size, maximum fuel particle size, minimum fuel particle size, and mean fuel particle size). The parametric studies use a set of contrived physical quantities (sometimes nonphysical) to show the effect of a single parameter. These tests verify that the code is functioning appropriately and help ensure that the sense and scale of the output response is appropriate for the parameter under study. In addition to the parameter-oriented validation tests, a simulation of the 1995 Cerro Negro eruption in Nicaragua was conducted so that TEPHRA results for ash thickness could be compared to measured values.

A previous validation test report (Winfrey, 2005) also compared TEPHRA output to the Cerro Negro eruption data. The tests in that report were performed on a Beowulf cluster using the Linux operating system, whereas tests in this report were performed on a multi-CPU SUN platform using the Unix operating system. In addition, Winfrey (2005) included several tests of the wind level, wind speed, and wind direction parameters and compared the TEPHRA code to the ASHPLUME code. The analyses in that report were based on ash mass per area quantities contained in one of the TEPHRA output files. However, most of the analyses contained in this report are postprocessed to use ash thickness as the basis for the test. This is because TEPHRA output is in kg m^{-2}, but postprocessing translates the output into ash thickness expressed in centimeters.

The scope of this validation is limited to validating the two plume model options (selected by setting their corresponding flag values): (i) [flag = 0], uniform distribution using a threshold value for the plume ratio, or (ii) [flag = 1], a lognormal distribution using the parameter beta (also β). The plume ratio is the ratio of the elevation of the bottom of the eruption plume to the elevation of the top of the plume, while beta specifies the particle distribution within the eruption column and helps determine where particles exit the column. While developing the validation test plan, staff determined that the probability map function and the survivor map function would not be included in the tests, because of their infrequent use. These are removed from calculations by setting their corresponding flag values to zero in the input configuration file. The parameters explicitly tested are the total eruptive mass, maximum particle size, minimum particle size, particle shape factor, vent height, maximum column height, fuel incorporation ratio, total eruptive fuel mass, diffusion, diffusion threshold, plume ratio, plume model, column beta, wind layers, wind speed, and wind file structure.

2 ENVIRONMENT

2.1 Hardware

The TEPHRA code runs on a Beowulf cluster (a networked set of computers dedicated to parallel computations) or a multi-CPU workstation with the OpenMPI message passing libraries. The tests contained in this document were performed at the Center for Nuclear Waste Regulatory Analyses (CNWRA) on the SUN Ultra-80 platform (hostname COYOTE) with 4 CPUs. There are from one to three client CPUs and one server.

The code is also actively run on a Beowulf cluster (hostname KATANA) at CNWRA with 20 CPUs. The Beowulf cluster has five machines, each containing two 2.4 GHz AMD dual core Opteron 2216, 1MB, X-64 processors. Each machine is equipped with an Ethernet card and connected to a 32-port switch. There are from 1 to 19 client CPUs and 1 server.

2.2 Software

The TEPHRA code runs in parallel mode with either the Linux or Unix operating system and the OpenMPI message passing libraries. Tables 2.2-1 and 2.2-2 provide the execution environment for their respective platforms.

The TEPHRA output files are not formatted for any particular application, but could be used by the Microsoft® Excel® spreadsheet application with minor adjustments. In addition, a trivial postprocessor (*t2t.e*) is available to convert the output to TECPLOT 360 input files. Most of the figures in this document were generated using the TECPLOT application on the BEMORE workstation at CNWRA.

Table 2.2-1. Required Software for the SUN Ultra-80

Software Necessary for Code Execution	Version Number
Operating System—Solaris	5.9
C compiler—gcc	3.4.2
MPI* compiler—mpicc	1.2.7
Open MPI (A portable MPI implementation)	1.2.7
*MPI = Message Passing Interface	

Table 2.2-2. Required Software for the Beowulf Cluster

Software Necessary for Code Execution	Version Number
Operating System—CentOS 4.4 (migrating to RedHat Linux)	9.0
OSCAR (Open Source Cluster Application Resources)	3.0
C compiler—gcc	3.4.6
MPI* compiler—mpicc	1.2.5
Open MPI (A portable MPI implementation)	1.2.5
*MPI = Message Passing Interface	

3 PREREQUISITES

Section 2 describes the prerequisites for the code environment. No special skills in volcanology, meteorology, or health physics are necessary to run the software. However, a basic understanding of these subjects would allow the user to select more meaningful ranges or values for key parameters.

4 ASSUMPTIONS AND CONSTRAINTS

It is assumed that an executable file of the TEPHRA code is available on the host machine. The executable file on COYOTE used for this validation exercise was obtained from Winfrey (2005).

5 TEST DESIGN

The tests are designed to run on the COYOTE Unix host machine in the following directory.

/home/janetzke/tephra/validation

Each of the 17 tests was executed in its own subdirectory with all necessary input files contained in the respective subdirectory. The following is a list of the 17 subdirectories:

t01-TotalAshMass
t02-MaxPartSize
t03-MinPartSize
t04-PartShapeFactor
t05-VentHeight
t06-MaxColumnHeight
t07-FuelIncorpRatio
t08-FuelMass
t09-Diffusion
t10-DiffusionThreshold
t11-PlumeRatio
t12-PlumeModel
t13-ColumnBeta
t14-WindLayers
t15-WindSpeed
t16-WindFile
CerroNegro

The TEPHRA code requires the following input files:

Configuration file (.**conf** extension)
Eruption file (.**erupt** extension)
Grid file (.**grid** extension)
Wind file (.**wind** extension)
Machine name file (.**mach** extension)—Beowulf cluster only

The execution of the validation tests on COYOTE only requires the first four input files, and these are described in Tables 5-1 through 5-4.

Table 5-1. TEPHRA Configuration Input File		
Parameter	**Description**	**Units**
SEED	Seed value for sequence of random numbers	—
DIFFUSION_COEFFICIENT	Diffusion coefficient for large particles	m^2/s
FALL_TIME_THRESHOLD	Threshold for change in diffusion	seconds fall time
LITHIC_DENSITY	Density model for the pyroclasts	kg/m^3
PUMICE_DENSITY	Density model for the pyroclasts	kg/m^3
COL_STEPS	Eruption column integration steps	—
PLUME_MODEL	0 = uniform distribution using a threshold at PLUME_RATIO 1 = lognormal distribution using beta	—
PLUME_RATIO	The bottom of laterally spreading ash cloud as ratio over total plume height	—
PROB_MAP	Will you be calculating a probability map? 0 = NO, 1 = YES	—
SURVIVOR	Create output for plotting a survivor function (ash accumulations from multiple eruption scenarios at one point using one or more wind profiles) 0 = NO, 1 = YES	—
ASH_ACCUM_THRESHOLD	Choose a threshold for an accumulation of ash (kg/m^2). The output will give the probability of exceeding this value.	—
PROB_THRESHOLD	Choose a percentage (0–100) of eruptions to consider. The output will give the ash accumulation (kg/m^2) at each point that is exceeded after this percentage of eruptions is considered.	—
MAX_ACCUMULATION	NO = 0, YES = 1 If YES, set a value for ASH_ACCUM_THRESHOLD	—
COMPLIMENT	NO = 0, YES = 1	—
WIND_INTERVAL	Distance between wind levels	meters
WIND_LEVELS	Number of wind levels	—
WIND_DAYS	Simulates a deposit using # eruption and # wind profile (here, # = 1)	—
WIND_COLUMNS	Value can be 3 or 5 3 = (height, speed, direction) 5 = (day, hour, height, speed, direction)	—

Table 5-2. TEPHRA Eruption Input File		
Parameter	**Description**	**Units**
volcano_northing	volcano location in UTM	meters
volcano_easting	volcano location in UTM	meters
total_ash_mass	total amount of tephra erupted	kg
max_part_size	maximum particle diameter considered	phi
min_part_size	minimum particle diameter considered	phi
part_mean_size	mean particle diameter erupted	phi
part_sigma_size	standard deviation in particle diameter	phi
part_shape_factor	shape factor for particle grains; F = (b+c)/2a, where a, b, and c are the length of the longest, middle, and shortest axes of the particle.*	—

Table 5-2. TEPHRA Eruption Input File (continued)		
Parameter	**Description**	**Units**
vent_height	elevation of the volcano vent above sea level	meters
max_column_height	eruption column height	meters
column_beta	parameter governing the particle size distribution in the eruption column	—
fuel_mass	total amount of fuel erupted	kg
fuel_max_size	maximum fuel diameter considered	$\log_{10}$(cm)
fuel_min_size	minimum fuel diameter considered	$\log_{10}$(cm)
fuel_mean_size	mean fuel diameter erupted	$\log_{10}$(cm)
incorporation_ratio	ratio of ash/waste particle sizes	—
initial_velocity	eruption exit velocity (at the vent)	m s
Suzuki. T. "A Theoretical Model for the Dispersion of Tephra. *Arc Volcanism: Physics and Tectonics*. D. Shimouru and I. Yokiyama, eds. Tokyo, Japan: Terra Scientific Publishing Company. pp. 99–100. 1983.		

Most of the TEPHRA input files are changed for at least one of the tests; however, the grid file is not changed for any test contained in this document. The grid file is a list of nodes at which calculation of tephra mass is desired. The grid coordinates should be consistent with the volcano position supplied in the eruption file. The grid file contains node points at 500-m [1,640-ft] separation in both UTM Easting and Northing directions. The lower left-hand node is (505000 Easting, 1370000 Northing), and the upper right-hand node is (535000 Easting, 1390000 Northing).

Table 5-3. TEPHRA Grid Input File		
Parameter	**Description**	**Units**
northing	Column 1: UTM Northing coordinate for node	meters
easting	Column 2: UTM Easting coordinate for node	meters

Table 5-4. TEPHRA Wind Input File		
Parameter	**Description**	**Units**
level_height	height of a wind layer in the eruption column	meters
wind_speed	wind speed for a specific wind height and direction	m/s
wind_direction	degrees_from_north (direction_TO)	degrees

The execution of a test is controlled by a script file that has the extension '.**run**'. This script (i) generates a time of execution file (.**time** extension), (ii) invokes the TEPHRA code with proper filenames as arguments, and (iii) converts the output to TECPLOT files with the *t2t.e* postprocessor.

The TEPHRA code generates the following output files:

Individual eruption mass per area listing (.**all** extension)
Cumulative eruption mass per area listing (.**cum** extension)

The format of these files is presented in Tables 5-5 and 5-6.

Table 5-5. TEPHRA Individual Eruption Listing File Format			
Field	**Parameter**	**Description**	**Units**
1	pt->northing	location in UTM (i.e., the y-axis)	meters
2	pt->easting	location in UTM (i.e., the x-axis)	meters
3	pt->ash_mass	calculated ash mass	kg/m^2
4	pt->fuel_mass	calculated fuel mass	kg/m^2

Table 5-6. TEPHRA Cumulative Eruption Listing File Format			
Field	**Parameter**	**Description**	**Units**
1	pt->northing	location in UTM (i.e., the y-axis)	meters
2	pt->easting	location in UTM (i.e., the x-axis)	meters
3	pt->cum_ash_mass	calculated ash mass	kg/m^2
4	pt->cum_fuel_mass	calculated fuel mass	kg/m^2
5	phi bin/mass*100	the grainsize distribution at this bin location...	—
6	phi bin/mass*100	the grainsize distribution at this bin location...	—
7	phi bin/mass*100	the grainsize distribution at this bin location...	—

The *t2t.e* postprocessor requires the following input files:

Individual eruption mass per area listing (.**all** extension)
Control parameter file (.**t2t** extension)
Surface-elevation file (.**height** extension)

The mass per area listing file is generated by the TEPHRA code and is used as input to the postprocessor. The control parameter file specifies the values for various *t2t.e* input parameters and is described in Table 5-7.

Table 5-7. *t2t.e* Postprocessor Control Parameter File		
Parameter	**Description**	**Units**
TECPLOT_TITLE	Title of TECPLOT input file generated as output from the postprocessor	text
LABEL_1	Text for label position 1	text
LABEL_2	Text for label position 2	text
LABEL_3	Text for label position 3	text
LABEL_4	Text for label position 4	text
TEPHRA_OUTPUT_FILE	File name of the TEPHRA output file used as input to the postprocessor	text
HEIGHT_PER_GRID_POINT_FILE	File name of the surface elevation file used as input to the postprocessor	text
MODE(individual;cumulative)	individual = process each eruption individually and place the results in separate zones for the TECPLOT application. cumulative = process the eruptions in the TEPHRA output file sequentially on a cumulative basis where the mass values are summed from one realization to the next over all realizations specified. The current summed data set after processing each eruption is written to a new zone for the TECPLOT application.	text

Table 5-7. *t2t.e* Postprocessor Control Parameter File (continued)		
Parameter	**Description**	**Units**
COORDINATE_SYSTEM(rectangular;cylindrical)	The generation of a TECPLOT application file requires the use of the "rectangular" coordinate system. The postprocessor can also generate an output file based on "cylindrical" coordinates; however, this file is not compatible with the TECPLOT application.	text
EOLIAN_AREA_LOWER_LEFT(x,y)	Specifies the lower left UTM point of the rectangular area to be output by the postprocessor	meters
EOLIAN_AREA_UPPER_RIGHT(x,y)	Specifies the upper right UTM point of the rectangular area to be output by the postprocessor.	meters
ERUPTION_RANGE	The start and end (start, end) eruptions in the TEPHRA output file to be processed by the postprocessor	integer
ERUPTIONS_IN_FILE	Total number of eruptions in the TEPHRA output file	integer
DENSITY_COEFFICIENTS	Density coefficients (a0, a1, a2) used to account for radial distance (r) from point of interest (vent location) in determining the ash density. ash density = $a0 + a1*e^{(a2*r)}$. The values used in this validation are a0 = 599.4 a1 = 865.6 a2 = 3.66e-4 They were extracted from a spreadsheet of field measurements.* For cases where kg/m^2 are desired rather than density, values of a0 = 100, a1 = 0, and a2 = 0 should be used.	real
POINT_OF_INTEREST(UTM)	Easting, Northing ordered pair specifying the vent location in UTM coordinates	meters
*Hill, B. "CN1295_Densities.xls." CNWRA Scientific Notebook #088. San Antonio, Texas: CNWRA. 1995.		

The surface-elevation file is constant for all tests and will not be described for each test. The content of the surface-elevation file is designed to specify a flat surface at 0 m [0 ft] elevation for the *t2t.e* postprocessor and is listed in Table 5-8.

Table 5-8. *t2t.e* Surface-Elevation Input File

```
ncols           3
nrows           2
xllcorner     504999.99998137
yllcorner     1370000.0000012
cellsize      10000
NODATA_value  -9999
0.0 0.0 0.0
0.0 0.0 0.0
```

The *t2t.e* postprocessor generates the following output file:

TECPLOT input file (.**tec** extension)

This file is formatted according to the requirements of the TECPLOT application (TECPLOT, 2006).

6 TEST RESULTS

6.1 Test Summary

Table 6.1-1 summarizes the tests contained in this validation report.

Table 6.1-1. Validation Test Summary

No.	ID	Parameter Name (Field Number)	File Name Containing Parameter	Parameter Description	Test Criterion	Test Results
1	t01	total_ash_mass (3)	**.erupt*	total mass erupted	The sum of the mass in the output file is consistent with the total ash erupted specified in the input file.	Pass
2	t02	max_part_size (4)	**.erupt*	maximum particle diameter	Smaller particles are transported farther than larger particle in a constant wind field.	Pass
3	t03	min_part_size (5)	**.erupt*	minimum particle diameter	The particle size input parameters effectively control the particle sizes contributing to the ash thickness.	Pass
4	t04	part_shape_factor (8)	**.erupt*	particle shape factor	Ash thickness is not affected significantly by the particle shape factor.	Pass
5	t05	vent_height (9)	**.erupt*	vent elevation above sea level	Eruptions of the same column size (vent to top of column) exhibit the same distribution pattern regardless of vent height.	Pass
6	t06	max_column_height (10)	**.erupt*	maximum ash column elevation above sea level	Higher columns, with a non-zero wind velocity, produce a more distal ash deposition pattern.	Pass
7	t07	incorporation_ratio (16)	**.erupt*	fuel incorporation ratio	The waste concentration in erupted tephra effects tephra transport and deposit characteristics.	Pass

Table 6.1-1. Validation Test Summary (continued)						
No.	**ID**	**Parameter Name (Field Number)**	**File Name Containing Parameter**	**Parameter Description**	**Test Criterion**	**Test Results**
8	t08	Uran (12)	**.erupt*	total mass of fuel erupted	The ash thickness is linearly associated to the total mass erupted.	Pass
9	t09	DIFFUSION_ COEFFICIENT	**.conf*	diffusion coefficient for large particles	A broader deposition pattern is calculated for larger diffusion coefficients.	Pass
10	t10	FALL_TIME_ THRESHOLD	**.conf*	fall time threshold for change in diffusion model	Shorter fall time particles show a more narrow diffusion pattern than that of longer fall time particles.	Pass
11	t11	PLUME_RATIO	**.conf*	the ratio of the elevation of the bottom of the plume to the maximum elevation of the plume	A larger plume ratio produces a more distal ash deposition pattern.	Pass
12	t12	PLUME_MODEL	**.conf*	selects either the uniform ash distribution model using the PLUME_RATI O or the lognormal distribution using column_beta	The appropriate model is selected based on the parameter value.	Pass
13	t13	column_beta (11)	**.erupt*	parameter governing the particle size distribution in the eruption column	Different column beta values for a relatively low column height produce minor variations in the calculated tephra deposit.	Pass
14	t14	level_height (1)	**.wind*	height of a wind layer in the eruption column	The direction of the wind at various levels appropriately affects the particles released at those levels.	Pass

Table 6.1-1. Validation Test Summary (continued)						
No.	**ID**	**Parameter Name (Field Number)**	**File Name Containing Parameter**	**Parameter Description**	**Test Criterion**	**Test Results**
15	t15	wind_speed (2)	**.wind*	wind speed for a specific wind height and direction	The ash deposition pattern for a zero velocity wind field is circular centered at the vent, while deposition patterns for a non-zero wind filed are elongated downwind of the vent.	Pass
16	t16	wind_direction (3)	**.wind*	degrees from north in which the wind is directed (direction_TO)	Particles released at one wind level are not affected by wind velocities at other wind levels.	Pass
17	CN			ground truth test using data from the Cerro Negro eruption of 1995	Calculated tephra thicknesses are reasonable when compared to measured thicknesses.	Pass

6.2 Test 1—Total Ash Mass

Objective

This test performs a mass balance check for the TEPHRA output. The mass per area point values supplied in the *t01.all* output file are contoured by the TECPLOT application, and a sum of the mass is obtained from the concentric isopachs generated as a result of setting the wind velocity values to zero.

Test Inputs

Table 6.2-1. TEPHRA Input File *t01.conf*

```
SEED                      6
DIFFUSION_COEFFICIENT  400.0
FALL_TIME_THRESHOLD   1080.0
LITHIC_DENSITY        2350.0
PUMICE_DENSITY        1100.0
COL_STEPS               50
PLUME_MODEL              0
PLUME_RATIO              0.001
PROB_MAP                 0
SURVIVOR                 0
ASH_ACCUM_THRESHOLD      0.0
PROB_THRESHOLD           0.0
MAX_ACCUMULATION         0
COMPLIMENT               0
WIND_INTERVAL          500.0
WIND_LEVELS               5
WIND_DAYS                1
WIND_COLUMNS             3
```

Table 6.2-2. TEPHRA Input File *t01.erupt*

```
1382530 532370 1000000000 -5.00  5.00 0.50 1 0.5 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1
100
```

Table 6.2-3. TEPHRA Input File *t01.wind*

```
0.0   0.0 -100.0
 500.0   0.0 -100.0
1000.0   0.0 -100.0
1500.0   0.0 -100.0
2000.0   0.0 -100.0
   ! Input file for program t2t.f90
!
TECPLOT_TITLE
  'TEPHRA Code Validation Run t01-TotalAshMass'
!
LABEL_1
  ' Validation Run t01-TotalAshMass'
!
LABEL_2
  ' Eruption = basecase.erupt'
!
LABEL_3
  ' Grid = basecase.grid'
!
LABEL_4
  ' Wind = t01.wind'
!
TEPHRA_OUTPUT_FILE
  't01.all'
!
HEIGHT_PER_GRID_POINT_FILE
  'basecase.height'
!
MODE(individual;cumulative)
  'individual'
!
COORDINATE_SYSTEM(rectangular;cylindrical)
  'rectangular'
!
EOLIAN_AREA_LOWER_LEFT(x,y)
  505000, 1370000
!
EOLIAN_AREA_UPPER_RIGHT(x,y)
  535000, 1390000
!
ERUPTION_RANGE(start,stop)
  1,1
!
ERUPTIONS_IN_FILE
  1
!
DENSITY_COEFFICIENTS
 100.0, 0.0, 0.0
!
POINT_OF_INTEREST(UTM)
 532370.0, 1382530.0
!
! END
```

Test Procedure

The script file for this test was run in subdirectory *t01-TotalAshMass* and is listed in Table 6.2-4.

Table 6.2-4. Test 01 Script File *t01.run*

```
date > t01.time
mpirun -np 1 \
      ../../tephra \
      t01.conf     \
      basecase.erupt  \
      basecase.grid   \
      t01.wind        \
      t01.all > t01.cum
date >> t01.time
../../tecplot/t2t/t2t.e <t01.t2t
mv t*.tec t01.tec
```

Test Results

The TECPLOT application file produced the display in Figure 6.2-1. The color scale units are kg/m^2. The sum of mass in the isopachs for Figure 6.2-1 should be consistent with the total amount of tephra erupted (10^9 kg) [2.2×10^9 lb] as specified in the eruption file. The spreadsheet in Table 6.2-5 was created to provide a total for the mass in Figure 6.2-1, and the value agrees with the input value to within 5 percent.

Test Rating

Pass

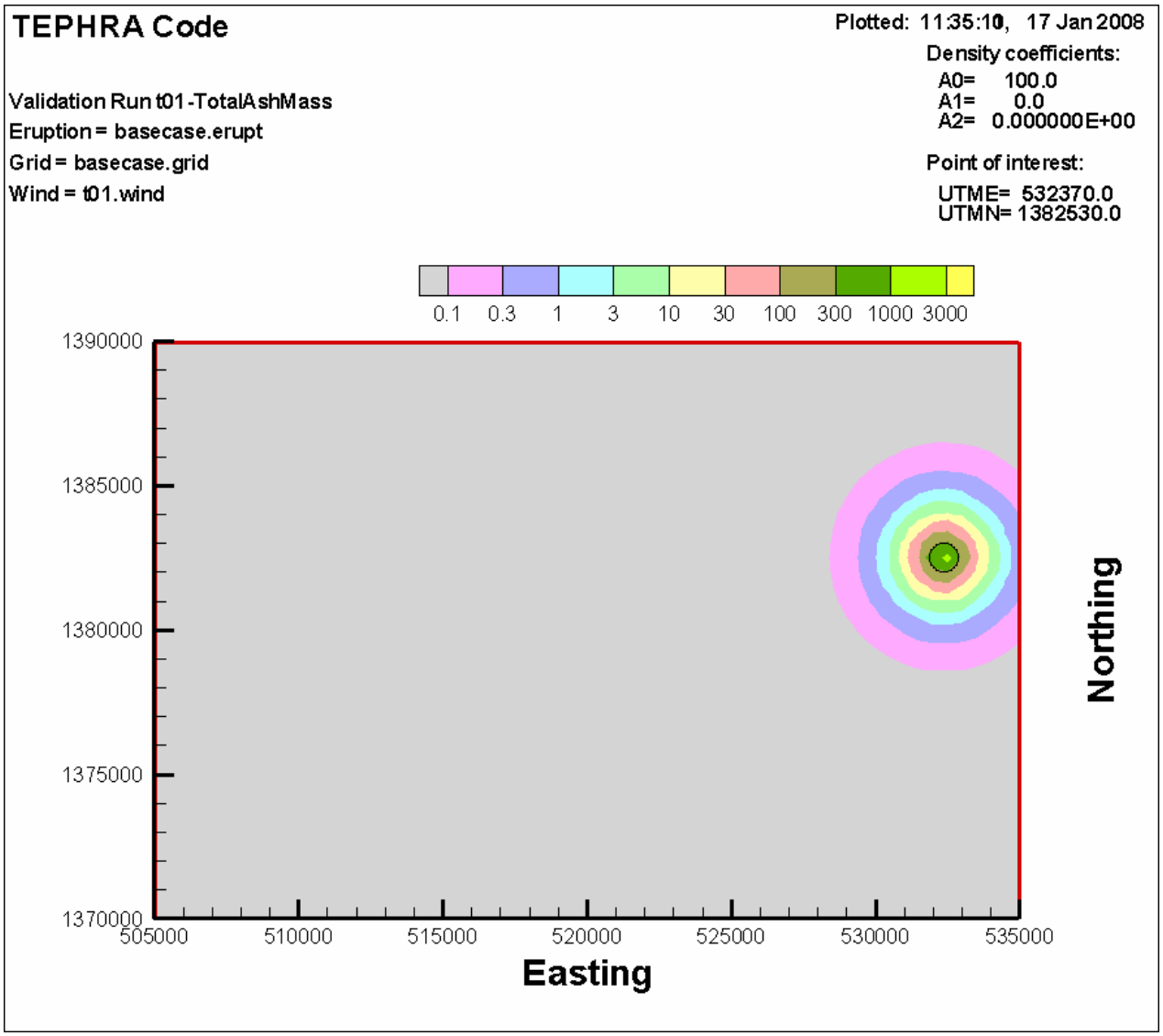


Figure 6.2-1. ***t01.tif***

Table 6.2-5. Spreadsheet for Mass Balance Test: TEPHRA Validation *Test t01-TotalAshMass*					
TEPHRA Output Mass per Area Contour Level (kg/m^2)	**Radius of Isopach (m)**	**Area of Isopach Circle (m^2)**	**Area of Isopach (m^2)**	**Representative Mass per Area for Isopach (kg m^−2)**	**Mass Per Isopach (kg)**
300	500	7.854E+05	7.854E+05	6.000E+02	4.712E+08
100	842	2.227E+06	1.442E+06	2.100E+02	3.028E+08
30	1180	4.374E+06	2.147E+06	6.000E+01	1.288E+08
10	1517	7.230E+06	2.855E+06	2.100E+01	5.996E+07
3	1854	1.080E+07	3.569E+06	6.000E+00	2.141E+07
1	2360	1.750E+07	6.699E+06	2.100E+00	1.407E+07
0.3	2865	2.579E+07	8.289E+06	6.000E-01	4.974E+06
0.1	3994	5.011E+07	2.433E+07	2.100E-01	5.109E+06
TOTAL	—	—	—	—	1.008E+09

6.3 Test 2—Maximum Particle Size

Objective

This test is designed to show the different tephra deposition patterns as a result of changing the maximum particle size participating in the eruption. The eruption file is used to control the specification of the maximum particle size. The mean particle size is also changed with the maximum particle size to maintain consistency in the input parameter set. The maximum particle size in phi units is reduced from −5 to 4 in 10 steps.

Because of the broad range of grain sizes found in many geologic materials, it is common to use a logarithmic transformation of grain diameters called the phi (Φ) scale

$$\Phi = -\log_2(d_{mm}) \tag{6.3-1}$$

for which d_{mm} is the grain diameter in millimeters [1 mm = 0.04 in]. For example, −2 Φ is equal to 4 mm [0.16 in] and 2 Φ is equal to 0.25 mm [0.01 in].

Test Inputs

Table 6.3-1. TEPHRA Input File *t02.conf*

```
SEED                      6
DIFFUSION_COEFFICIENT   400.0
FALL_TIME_THRESHOLD    1080.0
LITHIC_DENSITY         2350.0
PUMICE_DENSITY         1100.0
COL_STEPS                50
PLUME_MODEL               0
PLUME_RATIO               0.001
PROB_MAP                  0
SURVIVOR                  0
ASH_ACCUM_THRESHOLD       0.0
PROB_THRESHOLD            0.0
MAX_ACCUMULATION          0
COMPLIMENT                0
WIND_INTERVAL           500.0
WIND_LEVELS               5
WIND_DAYS                10
WIND_COLUMNS              3
```

Table 6.3-2. TEPHRA Input File *t02.erupt*

```
1382530 532370 1000000000 -5.00  5.00 0.50 1 0.5 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -4.00  5.00 0.50 1 0.5 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -3.00  5.00 1.00 1 0.5 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -2.00  5.00 1.50 1 0.5 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -1.00  5.00 2.00 1 0.5 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000  0.00  5.00 2.50 1 0.5 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000  1.00  5.00 3.00 1 0.5 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000  2.00  5.00 3.50 1 0.5 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000  3.00  5.00 4.00 1 0.5 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000  4.00  5.00 4.50 1 0.5 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
```

Table 6.3-3. TEPHRA Input File *t02.wind*

```
   0.0  10.0 -100.0
 500.0  10.0 -100.0
1000.0  10.0 -100.0
1500.0  10.0 -100.0
2000.0  10.0 -100.0
   0.0  10.0 -110.0
 500.0  10.0 -110.0
1000.0  10.0 -110.0
1500.0  10.0 -110.0
2000.0  10.0 -110.0
   0.0  10.0 -120.0
 500.0  10.0 -120.0
1000.0  10.0 -120.0
1500.0  10.0 -120.0
2000.0  10.0 -120.0
   0.0  10.0 -130.0
 500.0  10.0 -130.0
1000.0  10.0 -130.0
1500.0  10.0 -130.0
2000.0  10.0 -130.0
   0.0  10.0 -140.0
 500.0  10.0 -140.0
1000.0  10.0 -140.0
1500.0  10.0 -140.0
2000.0  10.0 -140.0
   0.0  10.0 -150.0
 500.0  10.0 -150.0
1000.0  10.0 -150.0
1500.0  10.0 -150.0
2000.0  10.0 -150.0
   0.0  10.0 -160.0
 500.0  10.0 -160.0
1000.0  10.0 -160.0
1500.0  10.0 -160.0
2000.0  10.0 -160.0
   0.0  10.0 -170.0
 500.0  10.0 -170.0
1000.0  10.0 -170.0
1500.0  10.0 -170.0
2000.0  10.0 -170.0
   0.0  10.0 -180.0
 500.0  10.0 -180.0
1000.0  10.0 -180.0
1500.0  10.0 -180.0
2000.0  10.0 -180.0
   0.0  10.0 -190.0
 500.0  10.0 -190.0
1000.0  10.0 -190.0
1500.0  10.0 -190.0
2000.0  10.0 -190.0
```

Table 6.3-4. *t2t.e* Postprocessor Input File *t02ind.t2t*

```
! Input file for program t2t.f90
!
TECPLOT_TITLE
  'TEPHRA Code Validation Run t02-MaxPartSize'
!
LABEL_1
  ' Validation Run t02-MaxPartSize'
!
LABEL_2
  ' Eruption = t02.erupt'
!
LABEL_3
  ' Grid = basecase.grid'
!
LABEL_4
  ' Wind = t02.wind'
!
TEPHRA_OUTPUT_FILE
  't02.all'
!
HEIGHT_PER_GRID_POINT_FILE
  'basecase.height'
!
MODE(individual;cumulative)
  'individual'
!
COORDINATE_SYSTEM(rectangular;cylindrical)
  'rectangular'
!
EOLIAN_AREA_LOWER_LEFT(x,y)
  505000, 1370000
!
EOLIAN_AREA_UPPER_RIGHT(x,y)
  535000, 1390000
!
ERUPTION_RANGE(start,stop)
  1,10
!
ERUPTIONS_IN_FILE
  10
!
DENSITY_COEFFICIENTS
 599.4,  865.6,  -3.66e-4
!
POINT_OF_INTEREST(UTM)
 532370.0, 1382530.0
!
! END
```

Test Procedure

The script file for this test was run in subdirectory *t02-MaxPartSize* and is listed in Table 6.3-5.

Table 6.3-5. Test 02 Script File *t02.run*

```
date > t02.time
mpirun -np 4 \
      ../../tephra \
      t02.conf     \
      t02.erupt  \
      basecase.grid   \
      t02.wind        \
      t02.all > t02.cum
date >> t02.time
../../tecplot/t2t/t2t.e <t02ind.t2t
mv t2t_ind*.tec t02ind.tec
../../tecplot/t2t/t2t.e <t02cum.t2t
mv t2t_cum*.tec t02cum.tec
```

The eruption input file is designed such that each eruption has a unique maximum particle size. Each eruption is paired with a set of wind parameters in the wind file that has a velocity vector in a different direction. This pairing results in a deposition pattern for each eruption that is at a different direction from the point of interest.

Test Results

As the particle sizes are restricted to smaller and smaller values, the tephra deposition pattern is expected to become more elongated when subjected to a significant wind field. Only 2 of the 10 cases are presented here, and they are representative of the entire set. The deposition pattern in Figure 6.3-2 indicates that the smaller particles are concentrated further from the point of interest than the larger particle size population in Figure 6.3-1.

Test Rating

Pass

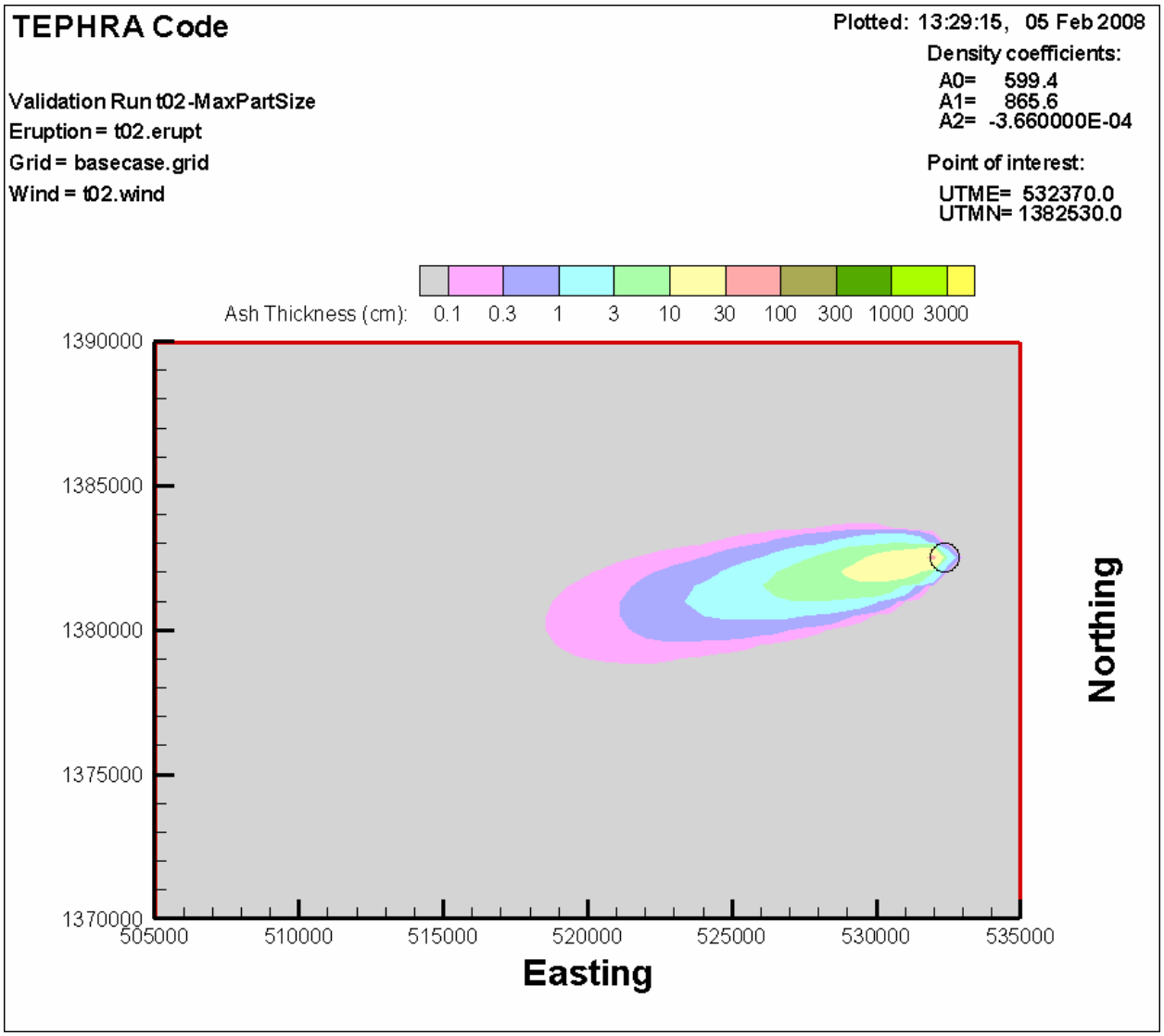


Figure 6.3-1. ***t02_ind_100.tif*** **[Maximum Particle Size Phi = −5]**

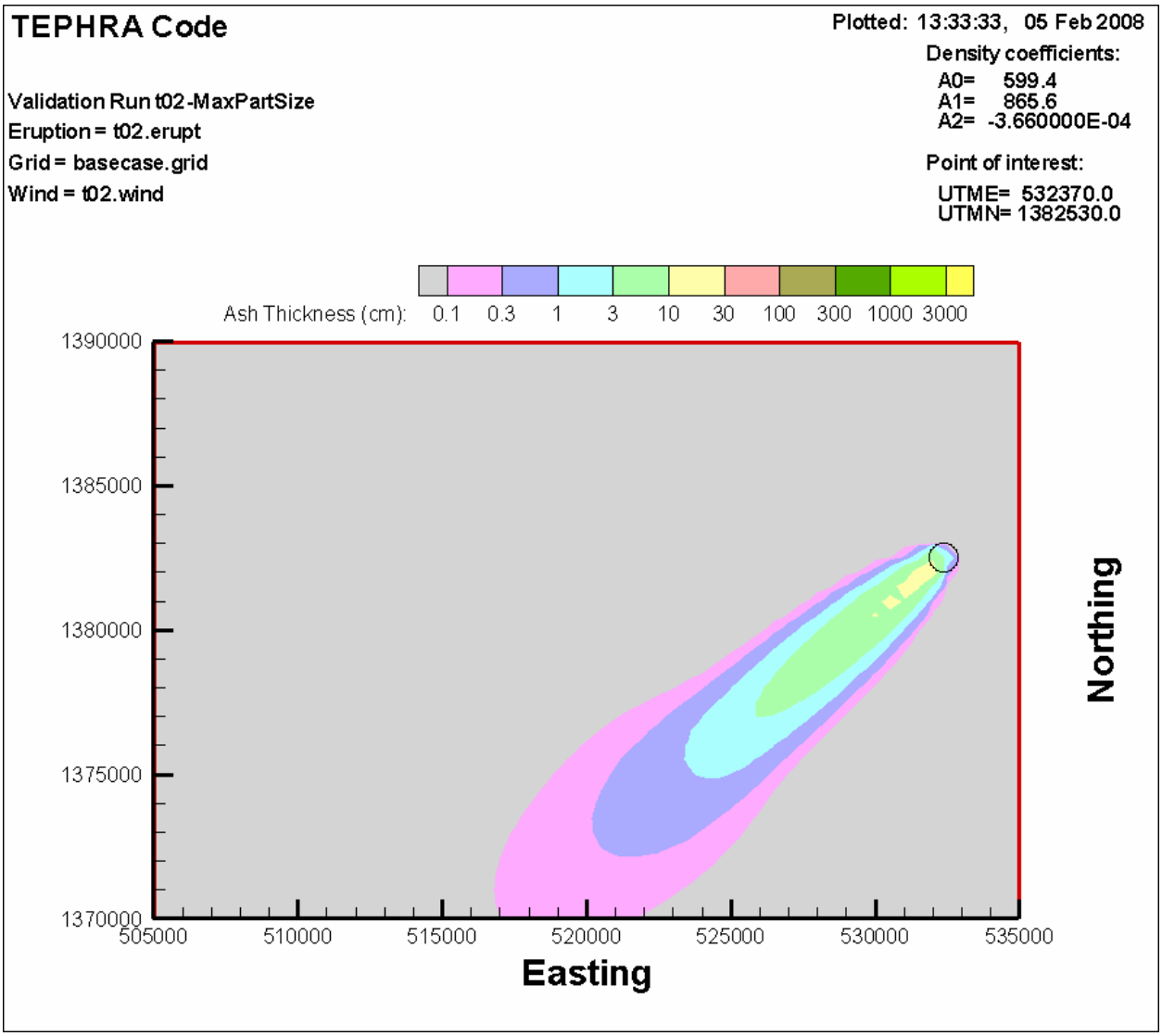


Figure 6.3-2. *t02_ind_130.tif* [Maximum Particle Size Phi = 4]

6.4 Test 3—Minimum Particle Size

Objective

This test is designed to show the different tephra deposition patterns as a result of changing the minimum particle size participating in the eruption. The eruption file is used to control the specification of the minimum particle size. The mean particle size is also changed with the minimum particle size to maintain consistency in the input parameter set. The minimum particle size in phi units is increased from −4 to 5 in 10 steps.

Test Inputs

Table 6.4-1 TEPHRA Input File *t03.conf*

```
SEED                      6
DIFFUSION_COEFFICIENT  400.0
FALL_TIME_THRESHOLD   1080.0
LITHIC_DENSITY        2350.0
PUMICE_DENSITY        1100.0
COL_STEPS               50
PLUME_MODEL              0
PLUME_RATIO              0.001
PROB_MAP                 0
SURVIVOR                 0
ASH_ACCUM_THRESHOLD      0.0
PROB_THRESHOLD           0.0
MAX_ACCUMULATION         0
COMPLIMENT               0
WIND_INTERVAL          500.0
WIND_LEVELS              5
WIND_DAYS               10
WIND_COLUMNS             3
```

Table 6.4-2. TEPHRA Input File *t03.erupt*

```
1382530 532370 1000000000 -5.00 -4.00 -4.50 1 0.5 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00 -3.00 -4.00 1 0.5 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00 -2.00 -3.50 1 0.5 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00 -1.00 -3.00 1 0.5 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  0.00 -2.50 1 0.5 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  1.00 -2.00 1 0.5 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  2.00 -1.50 1 0.5 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  3.00 -1.00 1 0.5 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  4.00 -0.50 1 0.5 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
```

Table 6.4-3. TEPHRA Input File *t03.wind*

```
   0.0  10.0 -100.0
 500.0  10.0 -100.0
1000.0  10.0 -100.0
1500.0  10.0 -100.0
2000.0  10.0 -100.0
   0.0  10.0 -110.0
 500.0  10.0 -110.0
1000.0  10.0 -110.0
1500.0  10.0 -110.0
2000.0  10.0 -110.0
   0.0  10.0 -120.0
 500.0  10.0 -120.0
1000.0  10.0 -120.0
1500.0  10.0 -120.0
2000.0  10.0 -120.0
   0.0  10.0 -130.0
 500.0  10.0 -130.0
1000.0  10.0 -130.0
1500.0  10.0 -130.0
2000.0  10.0 -130.0
   0.0  10.0 -140.0
 500.0  10.0 -140.0
1000.0  10.0 -140.0
1500.0  10.0 -140.0
2000.0  10.0 -140.0
   0.0  10.0 -150.0
 500.0  10.0 -150.0
1000.0  10.0 -150.0
1500.0  10.0 -150.0
2000.0  10.0 -150.0
   0.0  10.0 -160.0
 500.0  10.0 -160.0
1000.0  10.0 -160.0
1500.0  10.0 -160.0
2000.0  10.0 -160.0
   0.0  10.0 -170.0
 500.0  10.0 -170.0
1000.0  10.0 -170.0
1500.0  10.0 -170.0
2000.0  10.0 -170.0
   0.0  10.0 -180.0
 500.0  10.0 -180.0
1000.0  10.0 -180.0
1500.0  10.0 -180.0
2000.0  10.0 -180.0
   0.0  10.0 -190.0
 500.0  10.0 -190.0
1000.0  10.0 -190.0
1500.0  10.0 -190.0
2000.0  10.0 -190.0
```

Table 6.4-4. *t2t.e* Postprocessor Input File *t03.t2t*

```
! Input file for program t2t.f90
!
TECPLOT_TITLE
  'TEPHRA Code Validation Run t03-MinPartSize'
!
LABEL_1
  ' Validation Run t03-MinPartSize'
!
LABEL_2
  ' Eruption = t03.erupt'
!
LABEL_3
  ' Grid = basecase.grid'
!
LABEL_4
  ' Wind = t03.wind'
!
TEPHRA_OUTPUT_FILE
  't03.all'
!
HEIGHT_PER_GRID_POINT_FILE
  'basecase.height'
!
MODE(individual;cumulative)
  'individual'
!
COORDINATE_SYSTEM(rectangular;cylindrical)
  'rectangular'
!
EOLIAN_AREA_LOWER_LEFT(x,y)
  505000, 1370000
!
EOLIAN_AREA_UPPER_RIGHT(x,y)
  535000, 1390000
!
ERUPTION_RANGE(start,stop)
  1,10
!
ERUPTIONS_IN_FILE
  10
!
DENSITY_COEFFICIENTS
 599.4,  865.6,  -3.66e-4
!
POINT_OF_INTEREST(UTM)
 532370.0, 1382530.0
!
! END
```

Test Procedure

The script file for this test was run in subdirectory *t03-MinPartSize* and is listed in Table 6.4-5.

Table 6.4-5. Test 03 Script File *t03.run*

```
date > t03.time
mpirun -np 4 \
      ../../tephra \
      t03.conf     \
      t03.erupt  \
      basecase.grid   \
      t03.wind        \
      t03.all > t03.cum
date >> t03.time
../../tecplot/t2t/t2t.e <t03ind.t2t
mv t2t_ind*.tec t03ind.tec
../../tecplot/t2t/t2t.e <t03cum.t2t
mv t2t_cum*.tec t03cum.tec
```

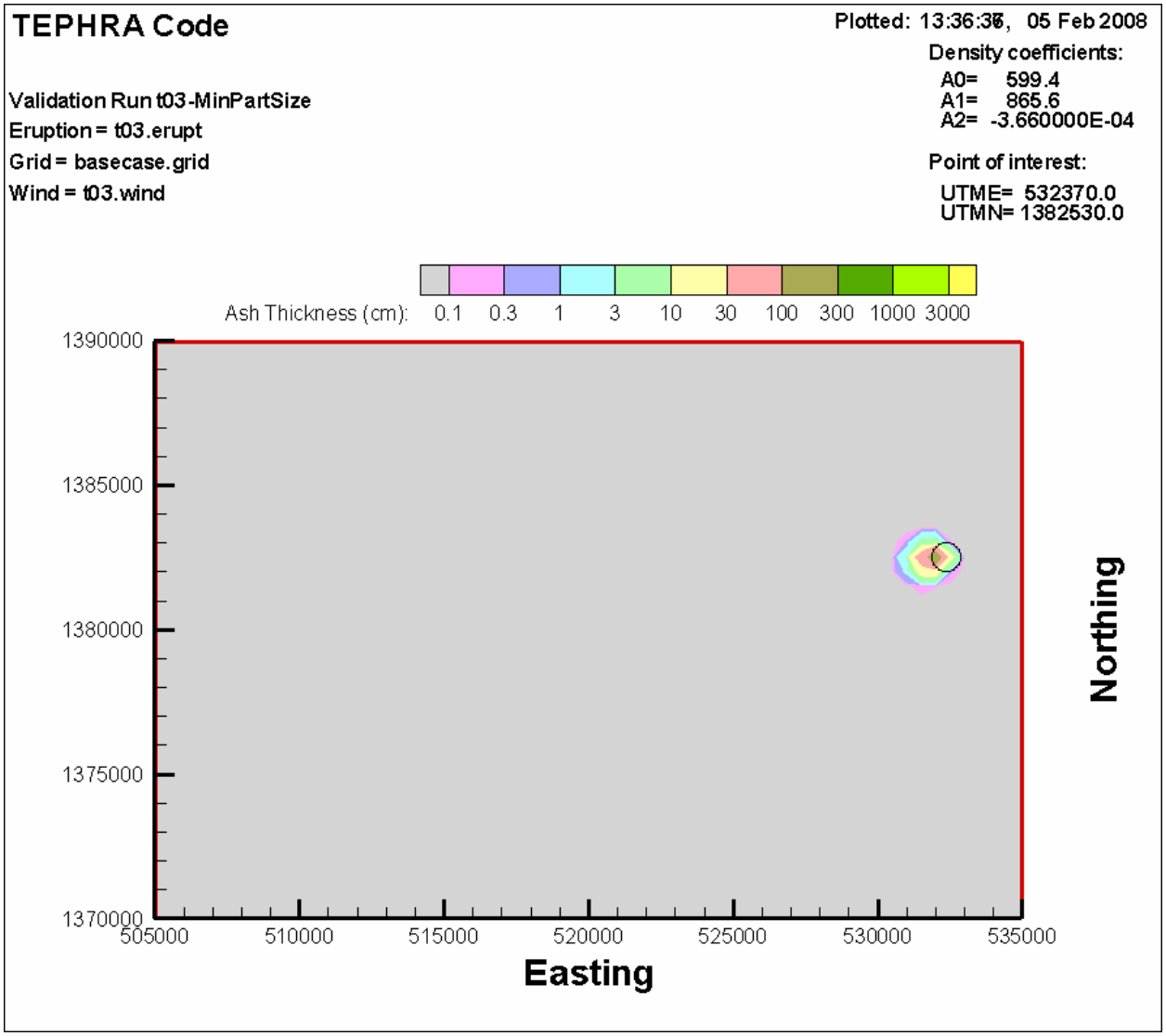
The eruption input file is designed such that each eruption has a unique minimum particle size. Each eruption is paired with a set of wind parameters in the wind file that has a velocity vector in a different direction. This pairing results in a deposition pattern for each eruption that is at a different direction from the point of interest.

Test Results

As the restriction on minimum particle sizes is relaxed, the tephra deposition pattern is expected to become more elongated when subjected to a significant wind field. Only 2 of the 10 cases are presented here, and they are representative of the entire set. The deposition pattern in Figure 6.4-2 indicates that the population of smaller particles is concentrated further from the point of interest than the larger particle size population in Figure 6.4-1. Note that the deposition pattern in Figure 6.4-2 is similar to that of Figure 6.3-1 except that the wind velocity vector rotates it by 90°.

Test Rating

Pass



.

Figure 6.4-1. ***t03_ind_100.tif*** **[Minimum Particle Size Phi = −4]**

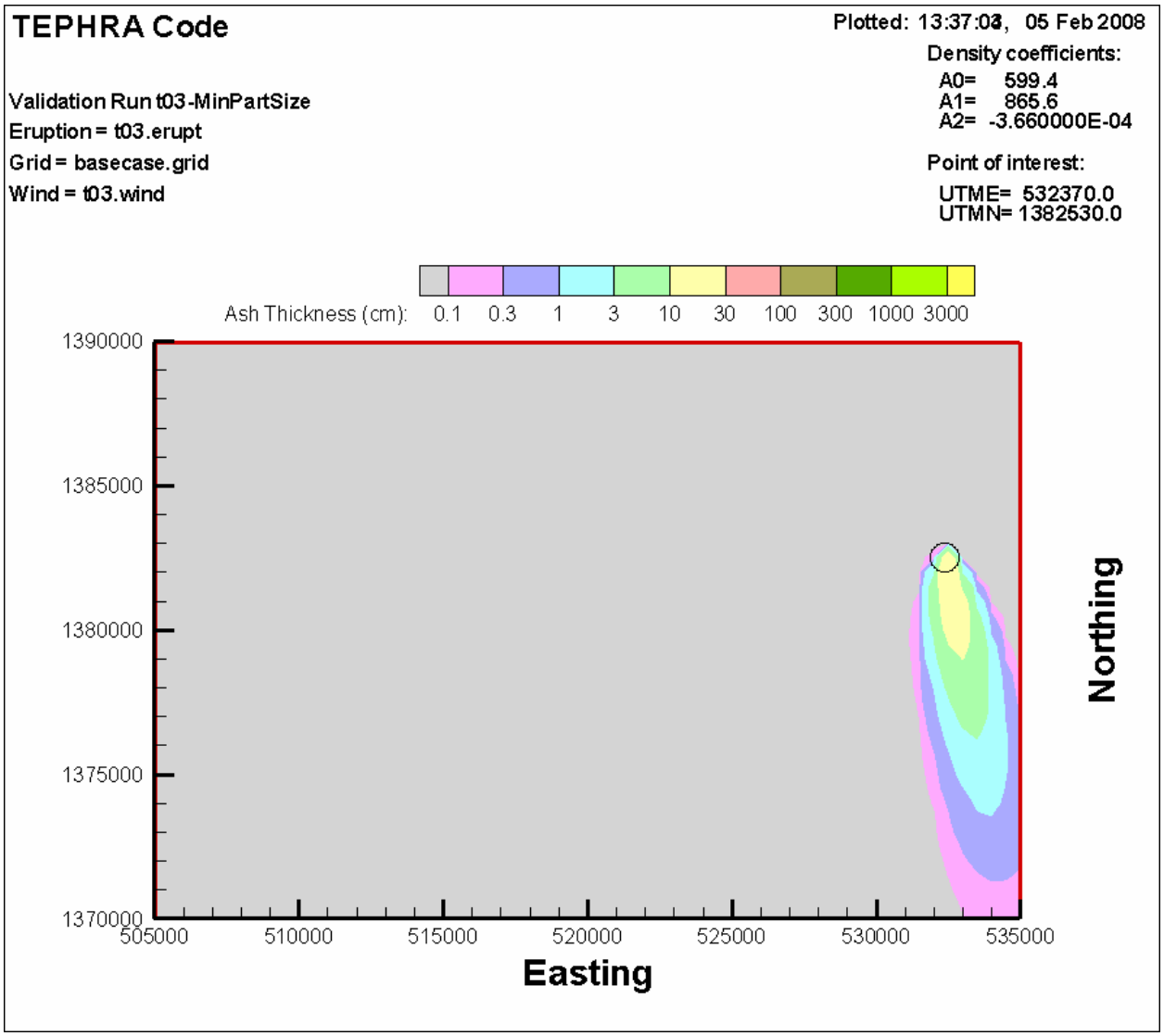


Figure 6.4-2. *t03_ind_190.tif* [Minimum Particle Size Phi = 5]

6.5 Test 4—Particle Shape Factor

Objective

The particle shape factor describes the shape of the ash particles being transported. It is not a significant parameter for ash deposition thickness, and no effect is anticipated in varying this parameter. This test is designed to reveal any changes in the tephra deposition patterns as a result of changing the particle shape factor. The eruption file is used to control the specification of the shape factor. The particle shape factor is increased from 0.1 to 1.0 in 10 steps.

Test Inputs

Table 6.5-1. TEPHRA Input File *t04.conf*

```
SEED                      6
DIFFUSION_COEFFICIENT   400.0
FALL_TIME_THRESHOLD    1080.0
LITHIC_DENSITY         2350.0
PUMICE_DENSITY         1100.0
COL_STEPS                50
PLUME_MODEL               0
PLUME_RATIO               0.001
PROB_MAP                  0
SURVIVOR                  0
ASH_ACCUM_THRESHOLD       0.0
PROB_THRESHOLD            0.0
MAX_ACCUMULATION          0
COMPLIMENT                0
WIND_INTERVAL           500.0
WIND_LEVELS               5
WIND_DAYS                10
WIND_COLUMNS              3
```

Table 6.5-2. TEPHRA Input File *t04.erupt*

```
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.1 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.2 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.3 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.4 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.6 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.7 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.8 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.9 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 1.0 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
```

Table 6.5-3. TEPHRA Input File *t04.wind*

```
   0.0  10.0 -100.0
 500.0  10.0 -100.0
1000.0  10.0 -100.0
1500.0  10.0 -100.0
2000.0  10.0 -100.0
   0.0  10.0 -110.0
 500.0  10.0 -110.0
1000.0  10.0 -110.0
1500.0  10.0 -110.0
2000.0  10.0 -110.0
   0.0  10.0 -120.0
 500.0  10.0 -120.0
1000.0  10.0 -120.0
1500.0  10.0 -120.0
2000.0  10.0 -120.0
   0.0  10.0 -130.0
 500.0  10.0 -130.0
1000.0  10.0 -130.0
1500.0  10.0 -130.0
2000.0  10.0 -130.0
   0.0  10.0 -140.0
 500.0  10.0 -140.0
1000.0  10.0 -140.0
1500.0  10.0 -140.0
2000.0  10.0 -140.0
   0.0  10.0 -150.0
 500.0  10.0 -150.0
1000.0  10.0 -150.0
1500.0  10.0 -150.0
2000.0  10.0 -150.0
   0.0  10.0 -160.0
 500.0  10.0 -160.0
1000.0  10.0 -160.0
1500.0  10.0 -160.0
2000.0  10.0 -160.0
   0.0  10.0 -170.0
 500.0  10.0 -170.0
1000.0  10.0 -170.0
1500.0  10.0 -170.0
2000.0  10.0 -170.0
   0.0  10.0 -180.0
 500.0  10.0 -180.0
1000.0  10.0 -180.0
1500.0  10.0 -180.0
2000.0  10.0 -180.0
   0.0  10.0 -190.0
 500.0  10.0 -190.0
1000.0  10.0 -190.0
1500.0  10.0 -190.0
2000.0  10.0 -190.0
```

Table 6.5-4. *t2t.e* Postprocessor Input File *t04ind.t2t*

```
! Input file for program t2t.f90
!
TECPLOT_TITLE
  'TEPHRA Code Validation Run t04-PartShapeFactor'
!
LABEL_1
  ' Validation Run t04-PartShapeFactor'
!
LABEL_2
  ' Eruption = t04.erupt'
!
LABEL_3
  ' Grid = basecase.grid'
!
LABEL_4
  ' Wind = t04.wind'
!
TEPHRA_OUTPUT_FILE
  't04.all'
!
HEIGHT_PER_GRID_POINT_FILE
  'basecase.height'
!
MODE(individual;cumulative)
  'individual'
!
COORDINATE_SYSTEM(rectangular;cylindrical)
  'rectangular'
!
EOLIAN_AREA_LOWER_LEFT(x,y)
  505000, 1370000
!
EOLIAN_AREA_UPPER_RIGHT(x,y)
  535000, 1390000
!
ERUPTION_RANGE(start,stop)
  1,10
!
ERUPTIONS_IN_FILE
  10
!
DENSITY_COEFFICIENTS
 599.4,  865.6,  -3.66e-4
!
POINT_OF_INTEREST(UTM)
 532370.0, 1382530.0
!
! END
```

Test Procedure

The script file for this test was run in subdirectory *t04-PartShapeFactor* and is listed in Table6.5-5.

Table 6.5-5. Test 04 Script File *t04.run*

```
date > t04.time
mpirun -np 4 \
      ../../tephra \
      t04.conf     \
      t04.erupt  \
      basecase.grid   \
      t04.wind        \
      t04.all > t04.cum
date >> t04.time
../../tecplot/t2t/t2t.e <t04ind.t2t
mv t2t_ind*.tec t04ind.tec
../../tecplot/t2t/t2t.e <t04cum.t2t
mv t2t_cum*.tec t04cum.tec
```

Test Results

The particle shape factor is not expected to significantly affect the tephra deposition pattern. This is consistent with the results shown in Figures 6.5-1 and 6.5-2. Despite the large difference in scale factor, there is little difference in the tephra pattern. The only difference in the two figures is the downwind deposition direction.

Test Rating

Pass

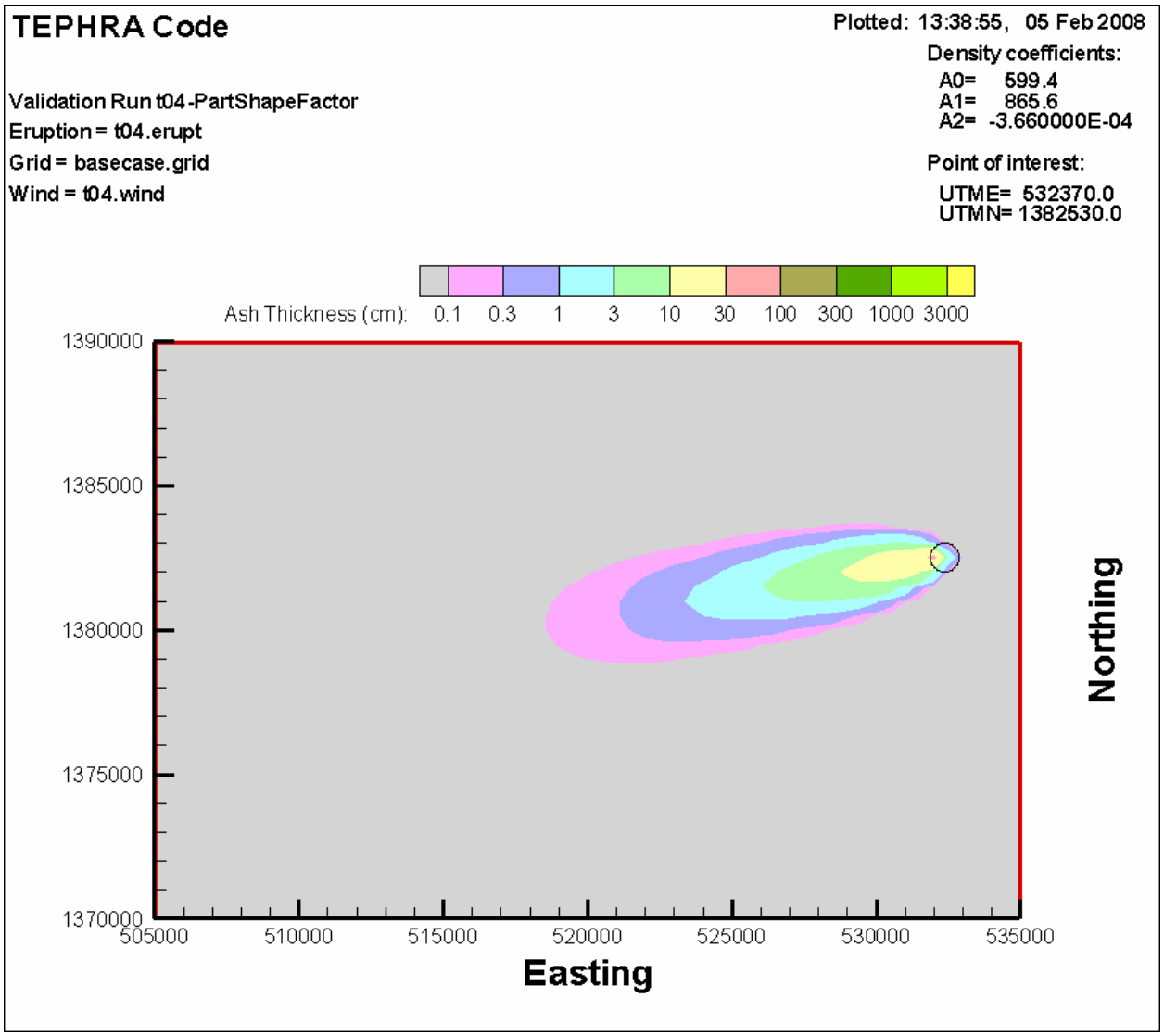


Figure 6.5-1. ***t04_ind_100.tif*** **[Particle Scale Factor = 0.1]**

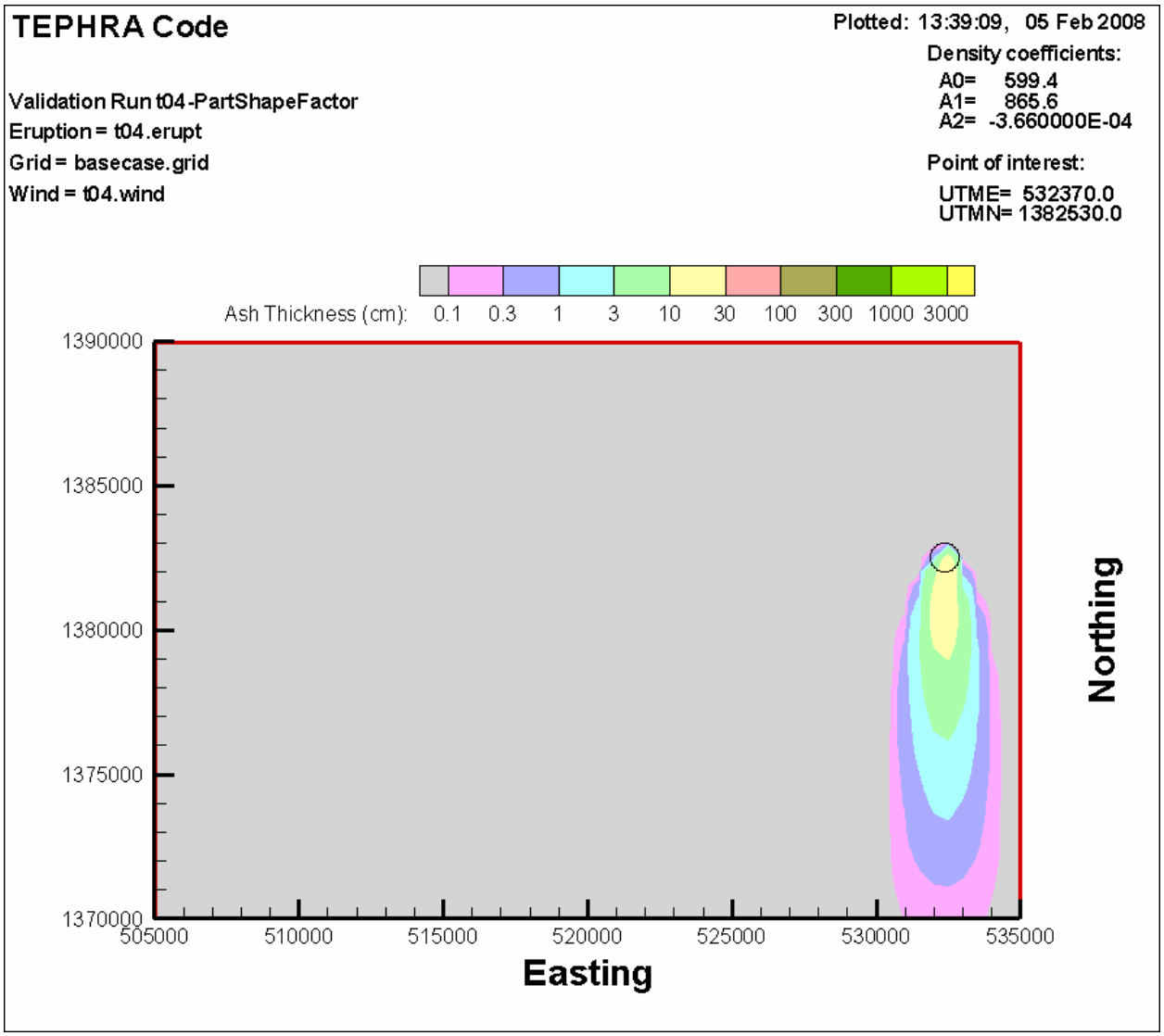


Figure 6.5-2. *t04_ind_180.tif* [Particle Scale Factor = 0.9]

6.6 Test 5—Vent Height

Objective

This test is designed to show the effect of vent height on the tephra deposition pattern. The eruption file is used to specify vent heights from 200 to 2,000 m [656 to 6,562 ft] in 10 steps while maintaining a constant column size of 2,000 m [6,562 ft]. Each vent height is paired with a wind velocity vector of a different direction.

Test Inputs

Table 6.6-1. TEPHRA Input File *t05.conf*

```
SEED                      6
DIFFUSION_COEFFICIENT   400.0
FALL_TIME_THRESHOLD    1080.0
LITHIC_DENSITY         2350.0
PUMICE_DENSITY         1100.0
COL_STEPS                50
PLUME_MODEL               0
PLUME_RATIO               0.001
PROB_MAP                  0
SURVIVOR                  0
ASH_ACCUM_THRESHOLD       0.0
PROB_THRESHOLD            0.0
MAX_ACCUMULATION          0
COMPLIMENT                0
WIND_INTERVAL           500.0
WIND_LEVELS               9
WIND_DAYS                10
WIND_COLUMNS              3
```

Table 6.6-2. TEPHRA Input File *t05.erupt*

```
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5 2000.0 4000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5 1800.0 3800.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5 1600.0 3600.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5 1400.0 3400.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5 1200.0 3200.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5 1000.0 3000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5  800.0 2800.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5  600.0 2600.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5  400.0 2400.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5  200.0 2200.00000  0.5 1000  -2 -4 -3 0.1 100
```

Table 6.6-3. TEPHRA Input File *t05.wind*

```
   0.0  10.0 -100.0
 500.0  10.0 -100.0
1000.0  10.0 -100.0
1500.0  10.0 -100.0
2000.0  10.0 -100.0
2500.0  10.0 -100.0
3000.0  10.0 -100.0
3500.0  10.0 -100.0
4000.0  10.0 -100.0
   0.0  10.0 -110.0
 500.0  10.0 -110.0
1000.0  10.0 -110.0
1500.0  10.0 -110.0
2000.0  10.0 -110.0
2500.0  10.0 -110.0
3000.0  10.0 -110.0
3500.0  10.0 -110.0
4000.0  10.0 -110.0
   0.0  10.0 -120.0
 500.0  10.0 -120.0
1000.0  10.0 -120.0
1500.0  10.0 -120.0
2000.0  10.0 -120.0
2500.0  10.0 -120.0
3000.0  10.0 -120.0
3500.0  10.0 -120.0
4000.0  10.0 -120.0
   0.0  10.0 -130.0
 500.0  10.0 -130.0
1000.0  10.0 -130.0
1500.0  10.0 -130.0
2000.0  10.0 -130.0
2500.0  10.0 -130.0
3000.0  10.0 -130.0
3500.0  10.0 -130.0
4000.0  10.0 -130.0
   0.0  10.0 -140.0
 500.0  10.0 -140.0
1000.0  10.0 -140.0
1500.0  10.0 -140.0
2000.0  10.0 -140.0
2500.0  10.0 -140.0
3000.0  10.0 -140.0
3500.0  10.0 -140.0
4000.0  10.0 -140.0
   0.0  10.0 -150.0
 500.0  10.0 -150.0
1000.0  10.0 -150.0
1500.0  10.0 -150.0
2000.0  10.0 -150.0
2500.0  10.0 -150.0
3000.0  10.0 -150.0
3500.0  10.0 -150.0
4000.0  10.0 -150.0
   0.0  10.0 -160.0
```

Table 6.6-3. TEPHRA Input File *t05.wind* (continued)

```
500.0  10.0 -160.0
1000.0  10.0 -160.0
1500.0  10.0 -160.0
2000.0  10.0 -160.0
2500.0  10.0 -160.0
3000.0  10.0 -160.0
3500.0  10.0 -160.0
4000.0  10.0 -160.0
   0.0  10.0 -170.0
 500.0  10.0 -170.0
1000.0  10.0 -170.0
1500.0  10.0 -170.0
2000.0  10.0 -170.0
2500.0  10.0 -170.0
3000.0  10.0 -170.0
3500.0  10.0 -170.0
4000.0  10.0 -170.0
   0.0  10.0 -180.0
 500.0  10.0 -180.0
1000.0  10.0 -180.0
1500.0  10.0 -180.0
2000.0  10.0 -180.0
2500.0  10.0 -180.0
3000.0  10.0 -180.0
3500.0  10.0 -180.0
4000.0  10.0 -180.0
   0.0  10.0 -190.0
 500.0  10.0 -190.0
1000.0  10.0 -190.0
1500.0  10.0 -190.0
2000.0  10.0 -190.0
2500.0  10.0 -190.0
3000.0  10.0 -190.0
3500.0  10.0 -190.0
4000.0  10.0 -190.0
```

Table 6.6-4. *t2t.e* Postprocessor Input File *t05ind.t2t*

```
!
LABEL_2
  ' Eruption = t05.erupt'
!
LABEL_3
  ' Grid = basecase.grid'
!
LABEL_4
  ' Wind = t05.wind (0-4000m)'
!
TEPHRA_OUTPUT_FILE
  't05.all'
!
HEIGHT_PER_GRID_POINT_FILE
  'basecase.height'
!
MODE(individual;cumulative)
  'individual'
!
```

Table 6.6-4. *t2t.e* Postprocessor Input File *t05ind.t2t* (continued)

```
COORDINATE_SYSTEM(rectangular;cylindrical)
  'rectangular'
!
EOLIAN_AREA_LOWER_LEFT(x,y)
  505000, 1370000
!
EOLIAN_AREA_UPPER_RIGHT(x,y)
  535000, 1390000
!
ERUPTION_RANGE(start,stop)
  1,10
!
ERUPTIONS_IN_FILE
  10
!
DENSITY_COEFFICIENTS
 599.4,  865.6,  -3.66e-4
!
POINT_OF_INTEREST(UTM)
 532370.0, 1382530.0
!
! END
```

Test Procedure

The script file for this test was run in subdirectory *t05-VentHeight* and is listed in Table 6.6-5.

Table 6.6-5. Test 05 Script File *t05.run*

```
date > t05.time
mpirun -np 4 \
      ../../tephra \
      t05.conf     \
      t05.erupt  \
      basecase.grid   \
      t05.wind        \
      t05.all > t05.cum
date >> t05.time
../../tecplot/t2t/t2t.e <t05ind.t2t
mv t2t_ind*.tec t05ind.tec
../../tecplot/t2t/t2t.e <t05cum.t2t
mv t2t_cum*.tec t05cum.tec
```

Test Results

The deposition pattern for columns of the same size is expected to be the same regardless of the vent height, because integration starts at the vent height and proceeds to the maximum column height. Ash fall below the vent height is not affected by wind or diffusion. This is shown to be the case as indicated by the contours in Figures 6.6-1 and 6.6-2. The lower vent height {400 m [1,312 ft]} has the same contour pattern except for the imposed varied wind direction.

Test Rating

Pass

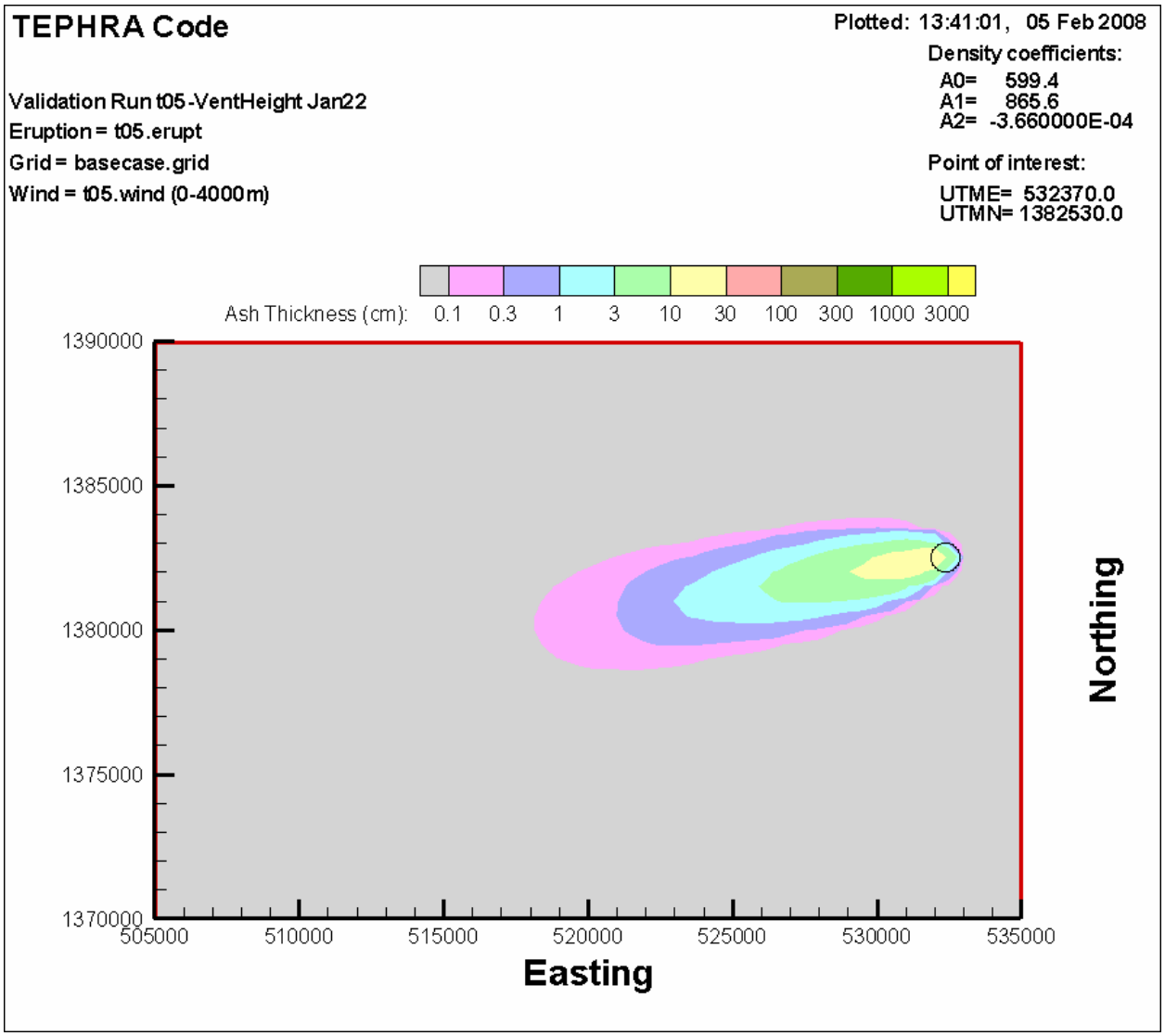


Figure 6.6-1. ***t05_ind_100.tif*** **{Vent Height = 2,000 m [6,562 ft]}**

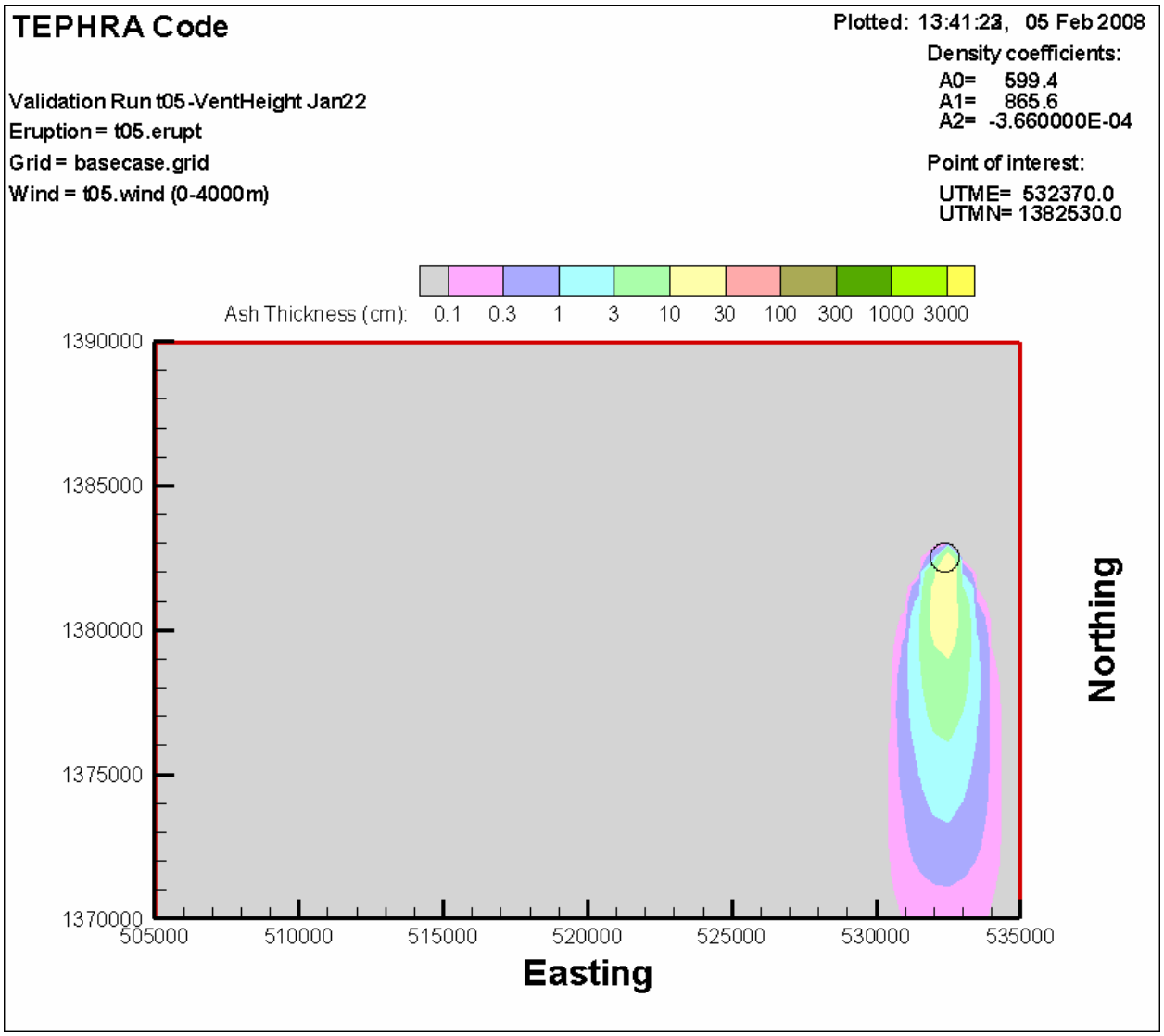


Figure 6.6-2. ***t05_ind_180.tif*** **{Vent Height = 400 m [1,312 ft]}**

6.7 Test 6—Maximum Column Height

Objective

This test is designed to show the effect of column height on the tephra deposition pattern. The eruption file is used to specify column heights from 500 to 5,000 m [1,640 to16,404 ft] in 10 steps. Each column height is paired with a wind velocity vector of a different direction. The taller column height eruption is expected to have a greater distal deposition pattern.

Test Inputs

Table 6.7-1. TEPHRA Input File *t06.conf*

```
SEED                      6
DIFFUSION_COEFFICIENT  400.0
FALL_TIME_THRESHOLD   1080.0
LITHIC_DENSITY        2350.0
PUMICE_DENSITY        1100.0
COL_STEPS               50
PLUME_MODEL              0
PLUME_RATIO              0.001
PROB_MAP                 0
SURVIVOR                 0
ASH_ACCUM_THRESHOLD      0.0
PROB_THRESHOLD           0.0
MAX_ACCUMULATION         0
COMPLIMENT               0
WIND_INTERVAL          500.0
WIND_LEVELS             11
WIND_DAYS               10
WIND_COLUMNS             3
```

Table 6.7-2. TEPHRA Input File *t06.erupt*

```
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 5000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 4500.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 4000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 3500.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 3000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 2500.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 1500.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 1000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0  500.00000  0.5 1000  -2 -4 -3 0.1 100
```

Table 6.7-3. TEPHRA Input File *t06.wind*

```
   0.0  10.0 -100.0
 500.0  10.0 -100.0
1000.0  10.0 -100.0
1500.0  10.0 -100.0
2000.0  10.0 -100.0
2500.0  10.0 -100.0
3000.0  10.0 -100.0
3500.0  10.0 -100.0
4000.0  10.0 -100.0
4500.0  10.0 -100.0
5000.0  10.0 -100.0
   0.0  10.0 -110.0
 500.0  10.0 -110.0
1000.0  10.0 -110.0
1500.0  10.0 -110.0
2000.0  10.0 -110.0
2500.0  10.0 -110.0
3000.0  10.0 -110.0
3500.0  10.0 -110.0
4000.0  10.0 -110.0
4500.0  10.0 -110.0
5000.0  10.0 -110.0
   0.0  10.0 -120.0
 500.0  10.0 -120.0
1000.0  10.0 -120.0
1500.0  10.0 -120.0
2000.0  10.0 -120.0
2500.0  10.0 -120.0
3000.0  10.0 -120.0
3500.0  10.0 -120.0
4000.0  10.0 -120.0
4500.0  10.0 -120.0
5000.0  10.0 -120.0
   0.0  10.0 -130.0
 500.0  10.0 -130.0
1000.0  10.0 -130.0
1500.0  10.0 -130.0
2000.0  10.0 -130.0
2500.0  10.0 -130.0
3000.0  10.0 -130.0
3500.0  10.0 -130.0
4000.0  10.0 -130.0
4500.0  10.0 -130.0
5000.0  10.0 -130.0
   0.0  10.0 -140.0
 500.0  10.0 -140.0
1000.0  10.0 -140.0
1500.0  10.0 -140.0
2000.0  10.0 -140.0
2500.0  10.0 -140.0
5000.0  10.0 -140.0
   0.0  10.0 -150.0
500.0  10.0 -150.0
1000.0  10.0 -150.0
1500.0  10.0 -150.0
```

Table 6.7-3. TEPHRA Input File *t06.wind* (continued)

```
2000.0  10.0 -150.0
2500.0  10.0 -150.0
3000.0  10.0 -150.0
3500.0  10.0 -150.0
4000.0  10.0 -150.0
4500.0  10.0 -150.0
5000.0  10.0 -150.0
   0.0  10.0 -160.0
 500.0  10.0 -160.0
1000.0  10.0 -160.0
1500.0  10.0 -160.0
2000.0  10.0 -160.0
2500.0  10.0 -160.0
3000.0  10.0 -160.0
3500.0  10.0 -160.0
4000.0  10.0 -160.0
4500.0  10.0 -160.0
5000.0  10.0 -160.0
   0.0  10.0 -170.0
 500.0  10.0 -170.0
1000.0  10.0 -170.0
1500.0  10.0 -170.0
2000.0  10.0 -170.0
2500.0  10.0 -170.0
3000.0  10.0 -170.0
3500.0  10.0 -170.0
4000.0  10.0 -170.0
4500.0  10.0 -170.0
5000.0  10.0 -170.0
   0.0  10.0 -180.0
 500.0  10.0 -180.0
1000.0  10.0 -180.0
1500.0  10.0 -180.0
2000.0  10.0 -180.0
2500.0  10.0 -180.0
3000.0  10.0 -180.0
3500.0  10.0 -180.0
4000.0  10.0 -180.0
4500.0  10.0 -180.0
5000.0  10.0 -180.0
   0.0  10.0 -190.0
500.0  10.0 -190.0
1000.0  10.0 -190.0
1500.0  10.0 -190.0
2000.0  10.0 -190.0
2500.0  10.0 -190.0
3000.0  10.0 -190.0
3500.0  10.0 -190.0
4000.0  10.0 -190.0
4500.0  10.0 -190.0
5000.0  10.0 -190.0
```

Table 6.7-4. *t2t.e* Postprocessor Input File *t06ind.t2t*

```
! Input file for program t2t.f90
!
TECPLOT_TITLE
  'TEPHRA Code Validation Run t06-MaxColumnHeight'
!
LABEL_1
  ' Validation Run t06-MaxColumnHeight Jan22'
!
LABEL_2
  ' Eruption = t06.erupt'
!
LABEL_3
  ' Grid = basecase.grid'
!
LABEL_4
  ' Wind = t06.wind (0-5000m)'
!
TEPHRA_OUTPUT_FILE
  't06.all'
!
HEIGHT_PER_GRID_POINT_FILE
  'basecase.height'
!
MODE(individual;cumulative)
  'individual'
!
COORDINATE_SYSTEM(rectangular;cylindrical)
  'rectangular'
!
EOLIAN_AREA_LOWER_LEFT(x,y)
  505000, 1370000
!
EOLIAN_AREA_UPPER_RIGHT(x,y)
  535000, 1390000
!
ERUPTION_RANGE(start,stop)
1,10
!
ERUPTIONS_IN_FILE
  10
!
DENSITY_COEFFICIENTS
 599.4,  865.6,  -3.66e-4
!
POINT_OF_INTEREST(UTM)
 532370.0, 1382530.0
!
! END
```

Test Procedure

The script file for this test was run in subdirectory *t06-MaxColumnHeight* and is listed in Table 6.7-5.

Table 6.7-5. Test 06 Script File *t06.run*

```
date > t06.time
mpirun -np 4 \
      ../../tephra \
      t06.conf     \
      t06.erupt  \
      basecase.grid   \
      t06.wind        \
      t06.all > t06.cum
date >> t06.time
../../tecplot/t2t/t2t.e <t06ind.t2t
mv t2t_ind*.tec t06ind.tec
../../tecplot/t2t/t2t.e <t06cum.t2t
mv t2t_cum*.tec t06cum.tec
```

Test Results

The isopachs in Figure 6.7-1 with the 5,000-m [16,404-ft] column height show a more distal deposition pattern than those in Figure 6.7-2 with a 1,000-m [3,281-ft] column height. This is consistent with the desired behavior.

Test Rating

Pass

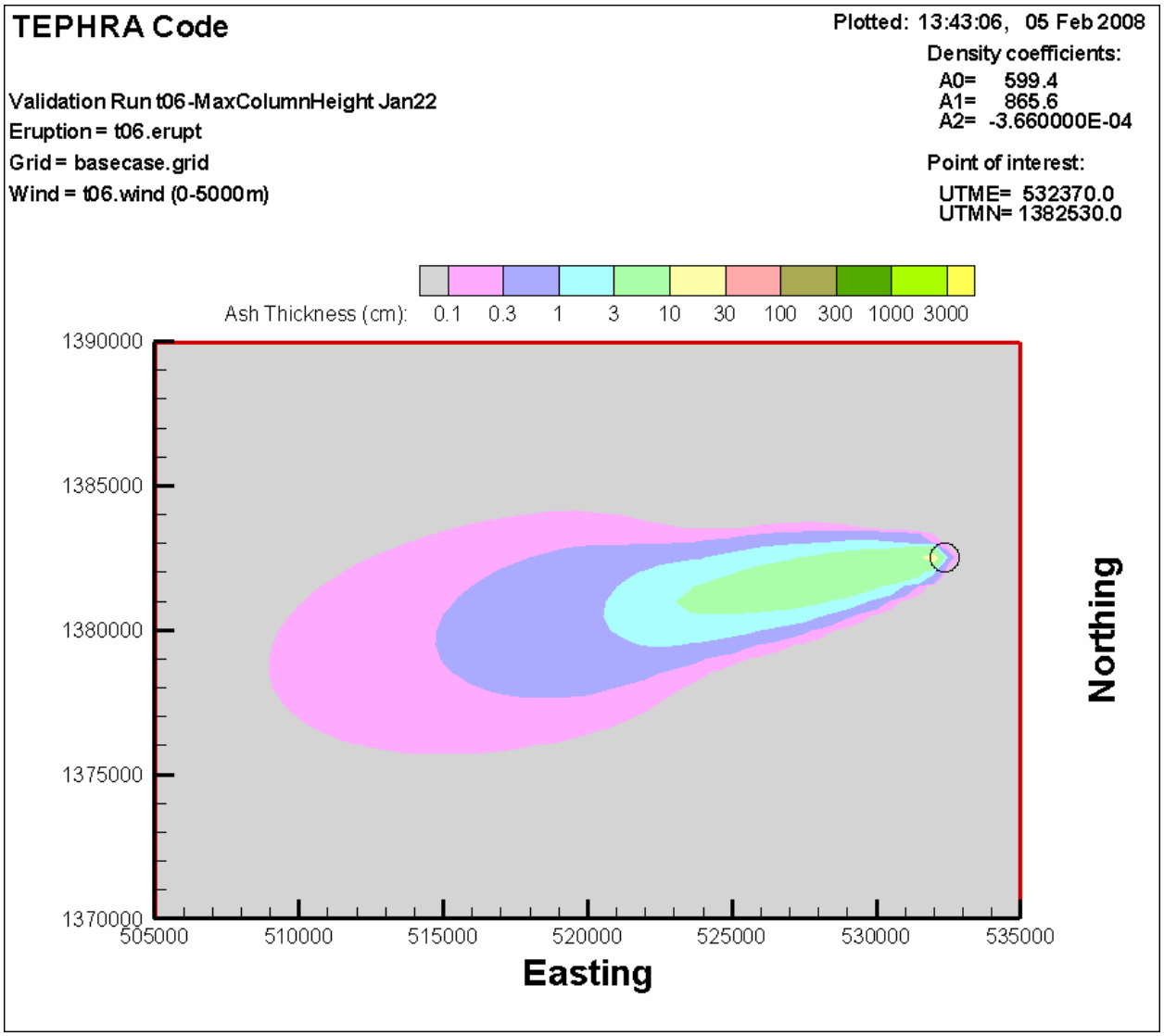


Figure 6.7-1. ***t06_ind_100.tif*** **{Maximum Column Height = 5,000 m [16,404 ft]}**

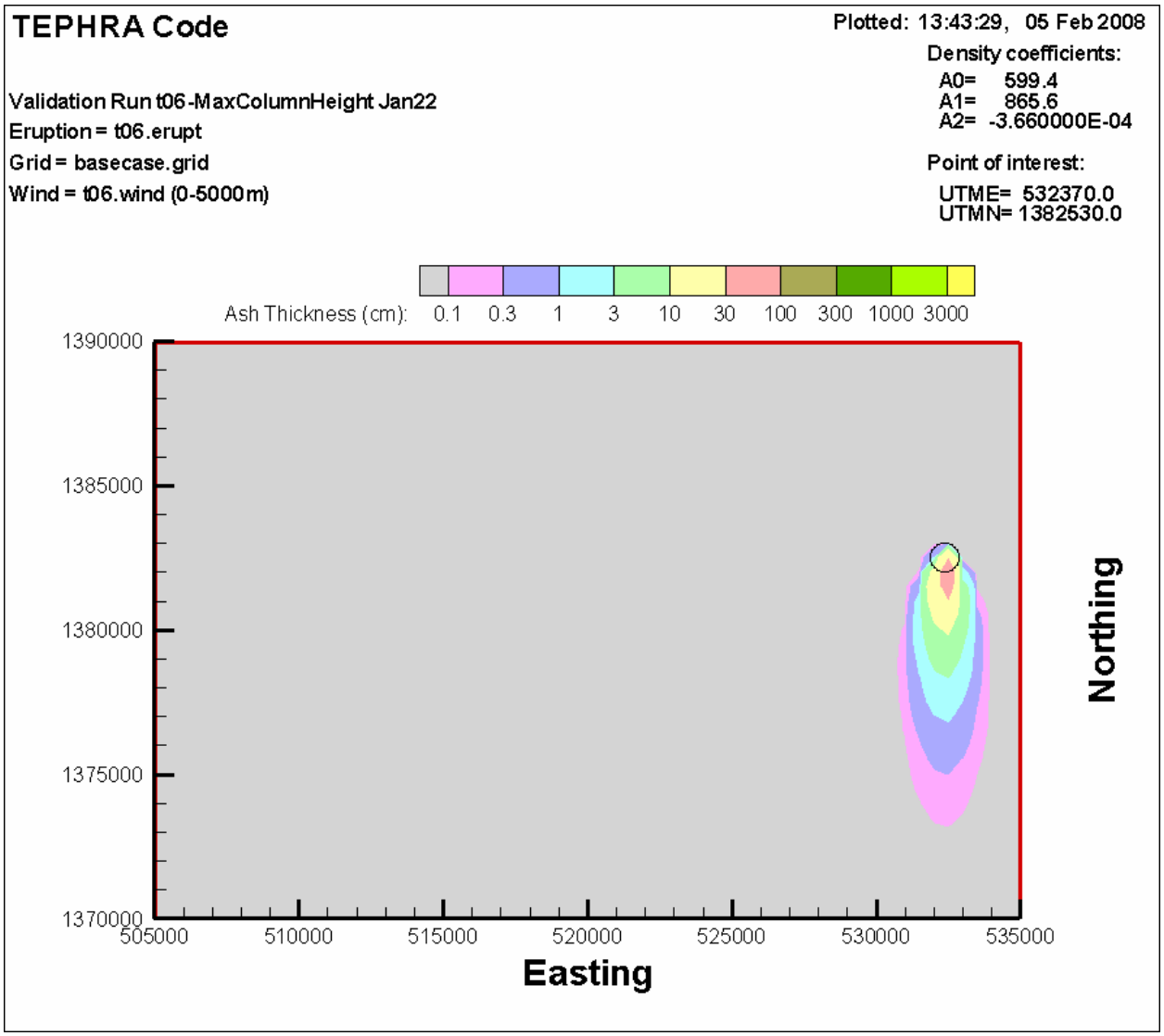


Figure 6.7-2. ***t06_ind_180.tif*** **{Maximum Column Height = 1,000 m [3,291 ft]}**

6.8 Test 7—Fuel Incorporation Ratio

Objective

This test is designed to show the effect of the incorporation ratio on the transport of combined particles of ash and spent nuclear fuel waste. The incorporation ratio equals the base-10 logarithm of the ratio of the minimum ash particle diameter to waste particle diameter for incorporation and combined transport. The three incorporation ratio values of 0.0, 0.6, and 1.0 for testing correspond to minimum ash particle diameters that are 1, 4, and 10 times larger than the waste particle diameter. Increasing the incorporation ratio has the effect of decreasing the density of fine particles consisting of ash and waste, because waste particles of much smaller diameters are permitted to be incorporated with an ash particle. As the combined particle density decreases and approaches the density for pure ash (i.e., negligible waste incorporation), increased transport distances for ash would be expected at distal regions. Because increasing waste composition in combined particles increases particle density and reduces transport distances, the waste concentration in ash (i.e., mass of waste per unit mass of ash) at distal regions is expected to decrease for increasing values of incorporation ratio.

Test Inputs

The total mass of ash was decreased, and the mass of spent nuclear fuel erupted was increased for this test so that incorporation ratio effects could be evaluated.

Table 6.8-1. TEPHRA Input File *t07.conf*

```
SEED                      6
DIFFUSION_COEFFICIENT   400.0
FALL_TIME_THRESHOLD    1080.0
LITHIC_DENSITY         2350.0
PUMICE_DENSITY         1100.0
COL_STEPS                50
PLUME_MODEL               0
PLUME_RATIO               0.001
PROB_MAP                  0
SURVIVOR                  0
ASH_ACCUM_THRESHOLD       0.0
PROB_THRESHOLD            0.0
MAX_ACCUMULATION          0
COMPLIMENT                0
WIND_INTERVAL             500.0
WIND_LEVELS                 5
WIND_DAYS                11
WIND_COLUMNS              3
```

Table 6.8-2. TEPHRA Input File *t07.erupt*

```
1382530 532370 10000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 1000000  -2 -4 -3 0.0 100
1382530 532370 10000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 1000000  -2 -4 -3 0.1 100
1382530 532370 10000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 1000000  -2 -4 -3 0.2 100
1382530 532370 10000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 1000000  -2 -4 -3 0.3 100
1382530 532370 10000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 1000000  -2 -4 -3 0.4 100
1382530 532370 10000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 1000000  -2 -4 -3 0.5 100
1382530 532370 10000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 1000000  -2 -4 -3 0.6 100
1382530 532370 10000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 1000000  -2 -4 -3 0.7 100
1382530 532370 10000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 1000000  -2 -4 -3 0.8 100
1382530 532370 10000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 1000000  -2 -4 -3 0.9 100
1382530 532370 10000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 1000000  -2 -4 -3 1.0 100
```

Table 6.8-3. TEPHRA Input File *t07.wind*

```
   0.0  10.0 -100.0
 500.0  10.0 -100.0
1000.0  10.0 -100.0
1500.0  10.0 -100.0
2000.0  10.0 -100.0
   0.0  10.0 -100.0
 500.0  10.0 -100.0
1000.0  10.0 -100.0
1500.0  10.0 -100.0
2000.0  10.0 -100.0
   0.0  10.0 -100.0
 500.0  10.0 -100.0
1000.0  10.0 -100.0
1500.0  10.0 -100.0
2000.0  10.0 -100.0
   0.0  10.0 -100.0
 500.0  10.0 -100.0
1000.0  10.0 -100.0
1500.0  10.0 -100.0
2000.0  10.0 -100.0
   0.0  10.0 -100.0
 500.0  10.0 -100.0
1000.0  10.0 -100.0
1500.0  10.0 -100.0
2000.0  10.0 -100.0
   0.0  10.0 -100.0
 500.0  10.0 -100.0
1000.0  10.0 -100.0
1500.0  10.0 -100.0
2000.0  10.0 -100.0
   0.0  10.0 -100.0
 500.0  10.0 -100.0
1000.0  10.0 -100.0
1500.0  10.0 -100.0
2000.0  10.0 -100.0
   0.0  10.0 -100.0
 500.0  10.0 -100.0
1000.0  10.0 -100.0
1500.0  10.0 -100.0
2000.0  10.0 -100.0
   0.0  10.0 -100.0
 500.0  10.0 -100.0
1000.0  10.0 -100.0
1500.0  10.0 -100.0
2000.0  10.0 -100.0
   0.0  10.0 -100.0
 500.0  10.0 -100.0
1000.0  10.0 -100.0
1500.0  10.0 -100.0
2000.0  10.0 -100.0
   0.0  10.0 -100.0
 500.0  10.0 -100.0
1000.0  10.0 -100.0
1500.0  10.0 -100.0
2000.0  10.0 -100.0
```

Table 6.8-4. *t2t.e* Postprocessor Input File *t07indmass.t2t*

```
! Input file for program t2t.f90
!
TECPLOT_TITLE
  'TEPHRA Code Validation Test t07-FuelIncorpRatio'
!
LABEL_1
  ' Validation Test t07-FuelIncorpRatio mass loading'
!
LABEL_2
  ' Eruption = t07.erupt'
!
LABEL_3
  ' Grid = basecase.grid'
!
LABEL_4
  ' Wind = t07.wind'
!
TEPHRA_OUTPUT_FILE
  't07.all'
!
HEIGHT_PER_GRID_POINT_FILE
  'basecase.height'
!
MODE(individual;cumulative)
  'individual'
!
COORDINATE_SYSTEM(rectangular;cylindrical)
  'rectangular'
!
EOLIAN_AREA_LOWER_LEFT(x,y)
  505000, 1370000
!
EOLIAN_AREA_UPPER_RIGHT(x,y)
  535000, 1390000
!
ERUPTION_RANGE(start,stop)
  1,11
!
ERUPTIONS_IN_FILE
  11
!
DENSITY_COEFFICIENTS
 100., 0., 0.
!
POINT_OF_INTEREST(UTM)
 532370.0, 1382530.0
!
! END
```

Test Procedure

The script file for this test was run in subdirectory *t07-FuelIncorpRatio* and is listed in Table 6.8-5.

Table 6.8-5. Test 07 Script File *t07.run*

```
date > t07.time
mpirun -np 4 \
      ../../tephra \
      t07.conf     \
      t07.erupt  \
      basecase.grid   \
      t07.wind        \
      t07.all > t07.cum
date >> t07.time
../../tecplot/t2t/t2t.e <t07ind.t2t
mv t2t_ind*.tec t07ind.tec
../../tecplot/t2t/t2t.e <t07cum.t2t
mv t2t_cum*.tec t07cum.tec
../../tecplot/t2t/t2t.e <t07indmass.t2t
mv t2t_ind*.tec t07indmassJan30.tec
```

Test Results

The outer isopachs in Figures 6.8-1 to 6.8-3 indicate a slightly farther ash transport for increasing incorporation ratios. Table 6.8-6 presents computed deposit characteristics for three sample locations (proximal, medial, and distal). Waste concentrations in ash (i.e., mass of waste per unit mass of ash) at distal regions were found to decrease for increasing values of incorporation ratio.

Masses of ash and waste deposited per unit area and mass of waste per unit mass of ash are presented in Table 6.8-6 for three different incorporation ratios and three proximities to the vent. Raw output data for masses per unit area were extracted from *t07indmass.tec* corresponding to the following three sample locations: proximal (530000 Easting, 13820000 Northing), medial (520000 Easting, 13820000 Northing), and distal (510000 Easting, 13820000 Northing). The calculated waste mass per unit ash mass equaled the waste mass per unit area divided by ash mass per unit area. These results are consistent with the desired behavior.

Test Rating

Pass

Table 6.8-6. Incorporation Ratio Effects

Incorporation Ratio (Unitless)	Location Type	Ash Mass Per Unit Area (kg/m^2)	Waste Mass Per Unit Area (kg/m^2)	Waste Mass Per Unit Ash Mass (Unitless)
0.0	Proximal	1.683	0.1757	0.104
	Medial	0.004605	0.0004810	0.104
	Distal	0.0001636	0.00001707	0.104
0.6	Proximal	1.685	0.1930	0.115
	Medial	0.004560	0.0004853	0.107
	Distal	0.0001650	0.00001553	0.094
1.0	Proximal	1.684	0.2113	0.125
	Medial	0.004664	0.0004105	0.088
	Distal	0.0001752	0.00001130	0.064

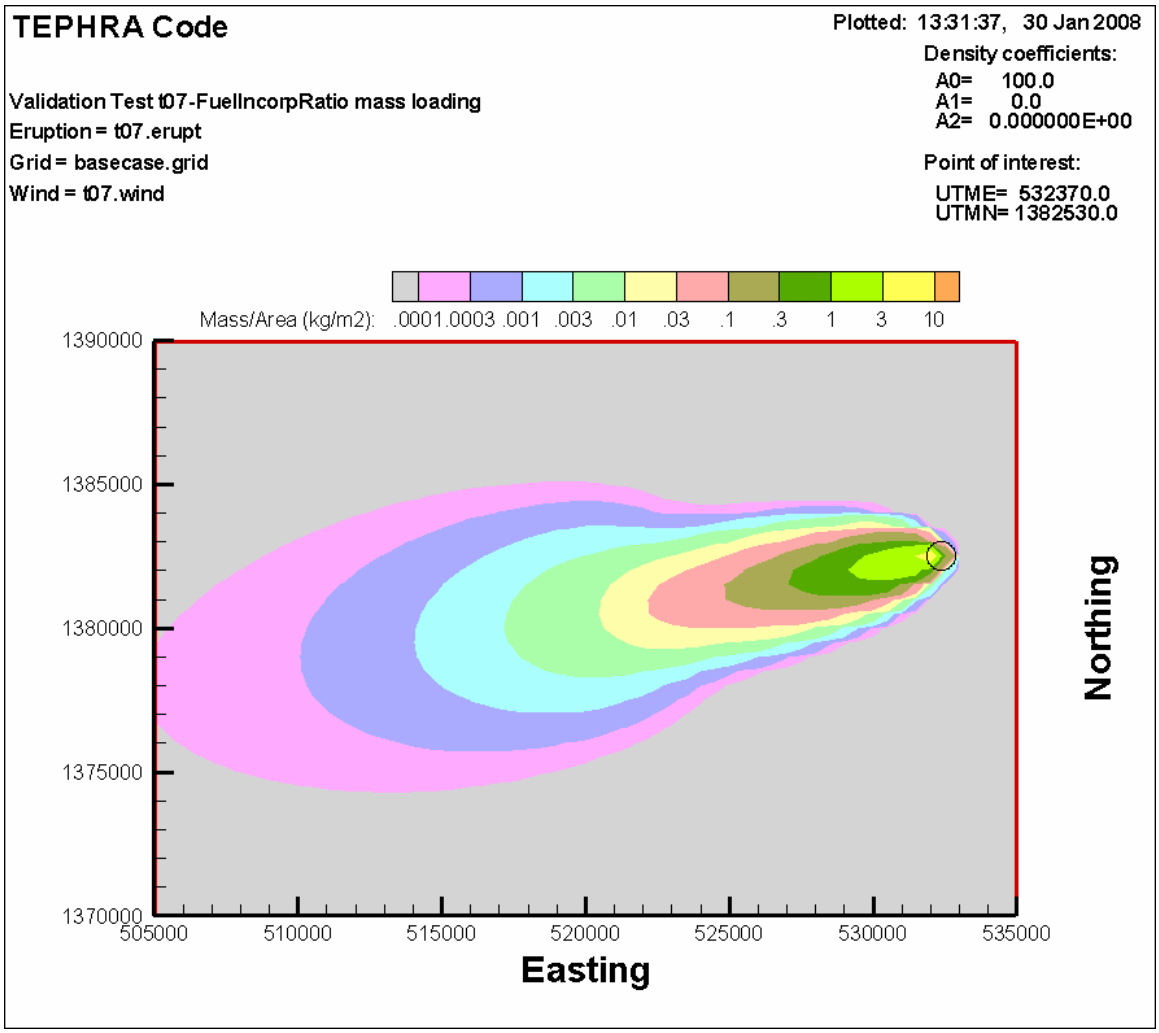


Figure 6.8-1. ***t07_indmass_1.tif*** **[Fuel Incorporation Ratio = 0.0]**

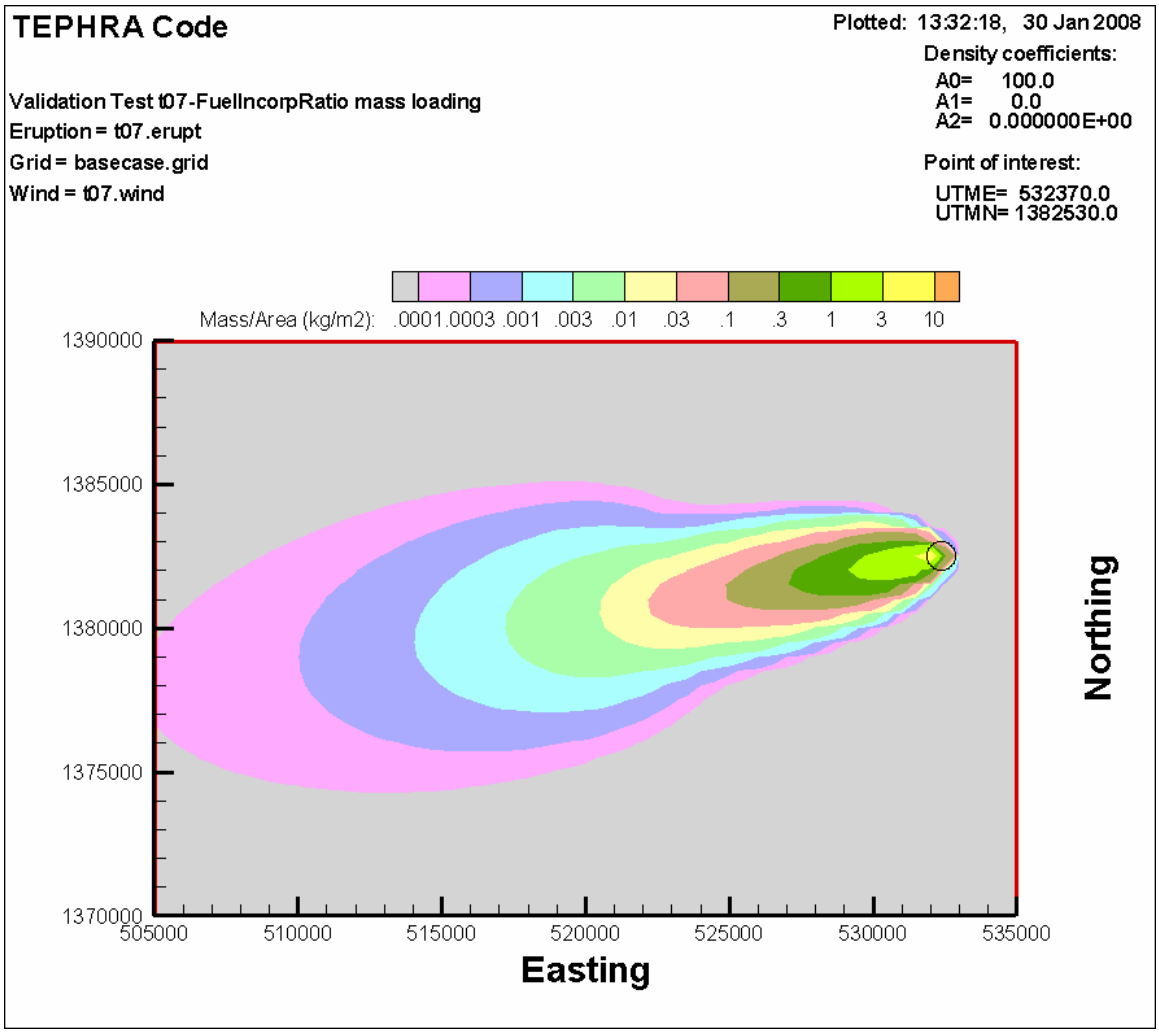


Figure 6.8-2. ***t07_indmass_7.tif*** **[Fuel Incorporation Ratio = 0.6]**

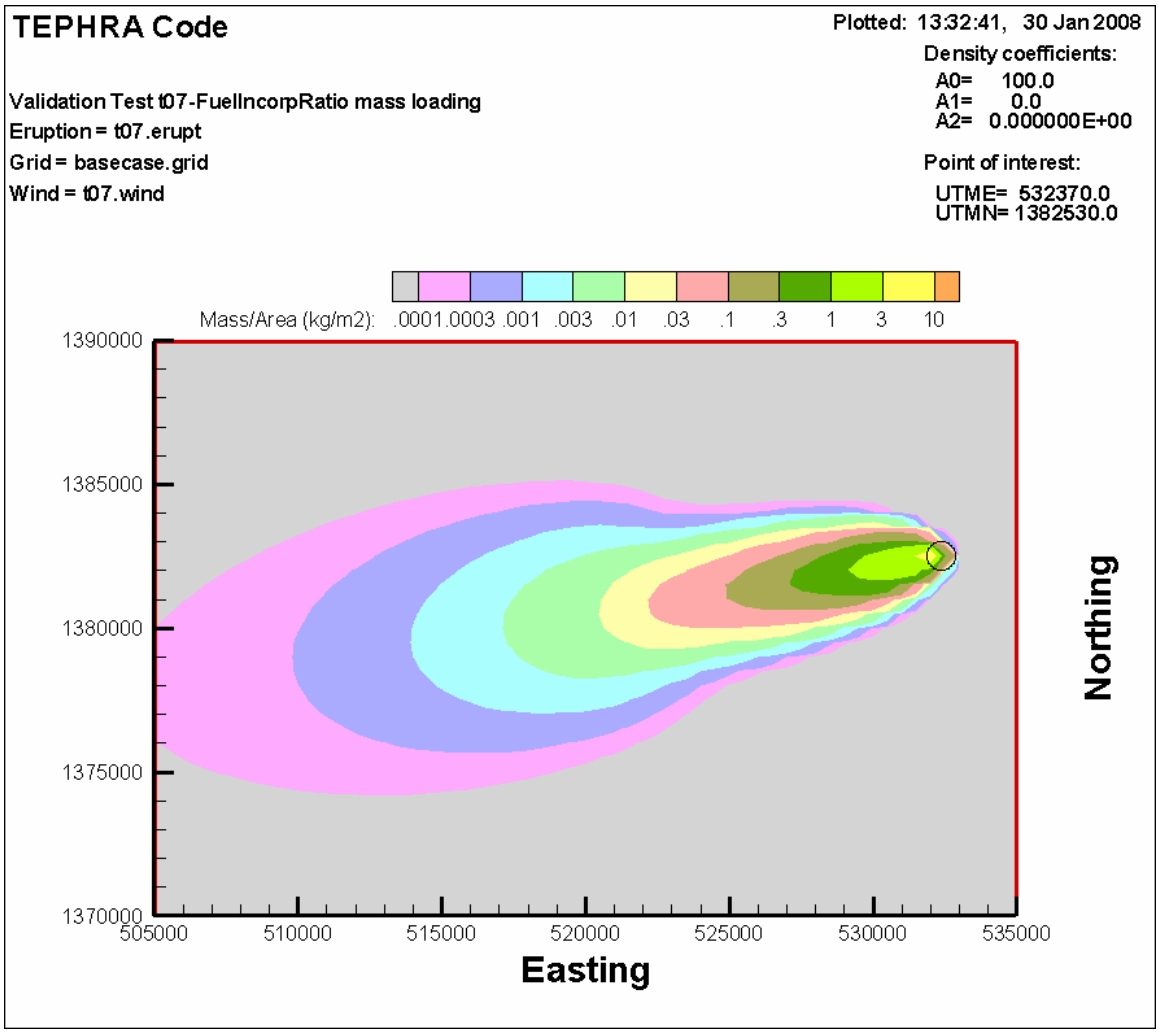


Figure 6.8-3. ***t07_indmass_11.tif*** **[Fuel Incorporation Ratio = 1.0]**

6.9 Test 8—Total Amount of Erupted Fuel Mass

Objective

This test is designed to show the effect of total erupted fuel on the fuel deposition pattern. The eruption file is used to specify total erupted fuel mass from 1,000 to 9,900 kg [2,205 to 21,826 lb] in 10 steps. Each ratio is paired with a wind velocity vector of a different direction.

Test Inputs

Table 6.9-1. TEPHRA Input File *t08.conf*

```
SEED                      6
DIFFUSION_COEFFICIENT   400.0
FALL_TIME_THRESHOLD    1080.0
LITHIC_DENSITY         2350.0
PUMICE_DENSITY         1100.0
COL_STEPS                50
PLUME_MODEL               0
PLUME_RATIO               0.001
PROB_MAP                  0
SURVIVOR                  0
ASH_ACCUM_THRESHOLD       0.0
PROB_THRESHOLD            0.0
MAX_ACCUMULATION          0
COMPLIMENT                0
WIND_INTERVAL           500.0
WIND_LEVELS               5
WIND_DAYS                10
WIND_COLUMNS              3
```

Table 6.9-2. TEPHRA Input File *t08.erupt*

```
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 1000  -2 -4 -3 0.5 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 2000  -2 -4 -3 0.5 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 3000  -2 -4 -3 0.5 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 4000  -2 -4 -3 0.5 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 5000  -2 -4 -3 0.5 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 6000  -2 -4 -3 0.5 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 7000  -2 -4 -3 0.5 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 8000  -2 -4 -3 0.5 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 9000  -2 -4 -3 0.5 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 9900  -2 -4 -3 1.5 100
```

Table 6.9-3. TEPHRA Input File *t08.wind*

```
   0.0  10.0 -100.0
 500.0  10.0 -100.0
1000.0  10.0 -100.0
1500.0  10.0 -100.0
2000.0  10.0 -100.0
   0.0  10.0 -110.0
 500.0  10.0 -110.0
1000.0  10.0 -110.0
1500.0  10.0 -110.0
2000.0  10.0 -110.0
   0.0  10.0 -120.0
 500.0  10.0 -120.0
1000.0  10.0 -120.0
1500.0  10.0 -120.0
2000.0  10.0 -120.0
   0.0  10.0 -130.0
 500.0  10.0 -130.0
1000.0  10.0 -130.0
1500.0  10.0 -130.0
2000.0  10.0 -130.0
   0.0  10.0 -140.0
 500.0  10.0 -140.0
1000.0  10.0 -140.0
1500.0  10.0 -140.0
2000.0  10.0 -140.0
   0.0  10.0 -150.0
 500.0  10.0 -150.0
1000.0  10.0 -150.0
1500.0  10.0 -150.0
2000.0  10.0 -150.0
   0.0  10.0 -160.0
 500.0  10.0 -160.0
1000.0  10.0 -160.0
1500.0  10.0 -160.0
2000.0  10.0 -160.0
   0.0  10.0 -170.0
 500.0  10.0 -170.0
1000.0  10.0 -170.0
1500.0  10.0 -170.0
2000.0  10.0 -170.0
   0.0  10.0 -180.0
 500.0  10.0 -180.0
1000.0  10.0 -180.0
1500.0  10.0 -180.0
2000.0  10.0 -180.0
   0.0  10.0 -190.0
 500.0  10.0 -190.0
1000.0  10.0 -190.0
1500.0  10.0 -190.0
2000.0  10.0 -190.0
```

Table 6.9-4. *t2t.e* Postprocessor Input File *t08.t2t*

```
! Input file for program t2t.f90
!
TECPLOT_TITLE
  'TEPHRA Code Validation Run t08-FuelMass'
!
LABEL_1
  ' Validation Run t08-FuelMass'
!
LABEL_2
  ' Eruption = t08.erupt'
!
LABEL_3
  ' Grid = basecase.grid'
!
LABEL_4
  ' Wind = t08.wind'
!
TEPHRA_OUTPUT_FILE
  't08.all'
!
HEIGHT_PER_GRID_POINT_FILE
  'basecase.height'
!
MODE(individual;cumulative)
  'individual'
!
COORDINATE_SYSTEM(rectangular;cylindrical)
  'rectangular'
!
EOLIAN_AREA_LOWER_LEFT(x,y)
  505000, 1370000
!
EOLIAN_AREA_UPPER_RIGHT(x,y)
  535000, 1390000
!
ERUPTION_RANGE(start,stop)
  1,10
!
ERUPTIONS_IN_FILE
  10
!
DENSITY_COEFFICIENTS
 599.4,  865.6,  -3.66e-4
!
POINT_OF_INTEREST(UTM)
 532370.0, 1382530.0
!
! END
```

Test Procedure

The script file for this test was run in subdirectory *t08-FuelMass* and is listed in Table 6.9-5.

Table 6.9-5. Test 08 Script File *t08.run*

```
date > t08.time
mpirun -np 4 \
      ../../tephra \
      t08.conf     \
      t08.erupt  \
      basecase.grid   \
      t08.wind        \
      t08.all > t08.cum
date >> t08.time
../../tecplot/t2t/t2t.e <t08ind.t2t
mv t2t_ind*.tec t08ind.tec
../../tecplot/t2t/t2t.e <t08cum.t2t
mv t2t_cum*.tec t08cum.tec
```

Test Results

The larger total fuel mass eruption is expected to have a larger amount of fuel deposited despite equal amounts of ash deposited. The isopachs in Figure 6.9-1 represent an order of magnitude less fuel deposited at any given point than those of Figure 6.9-2. This is consistent with the total mass of erupted fuel of 1,000 kg [2,205 lb] in Figure 6.9-1 and 9,000 kg [19,841 lb] in Figure 6.9-2.

Test Rating

Pass

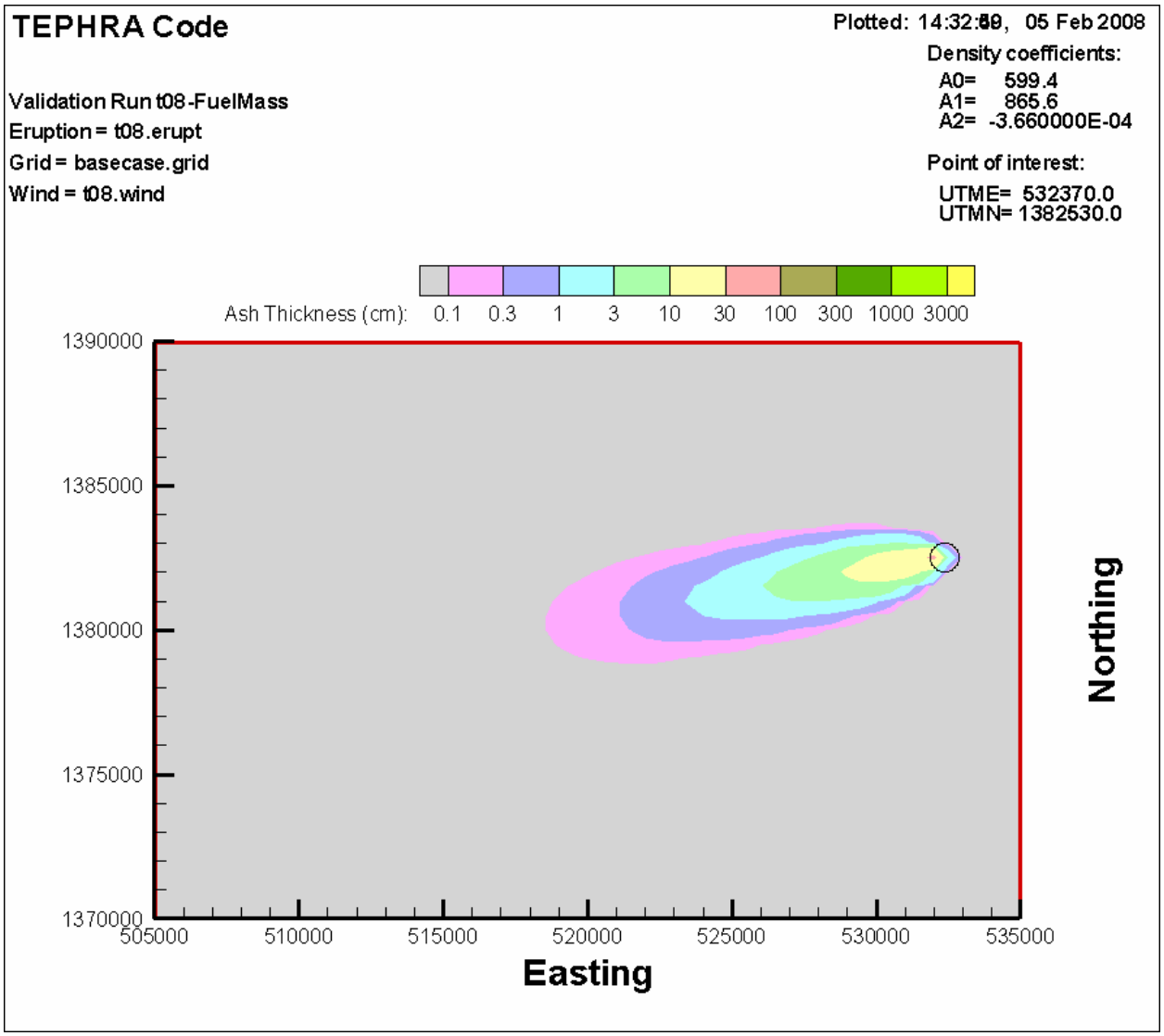


Figure 6.9-1. ***t08_ind_100.tif*** **{Total Erupted Fuel Mass = 1,000 kg [2,205 lb]}**

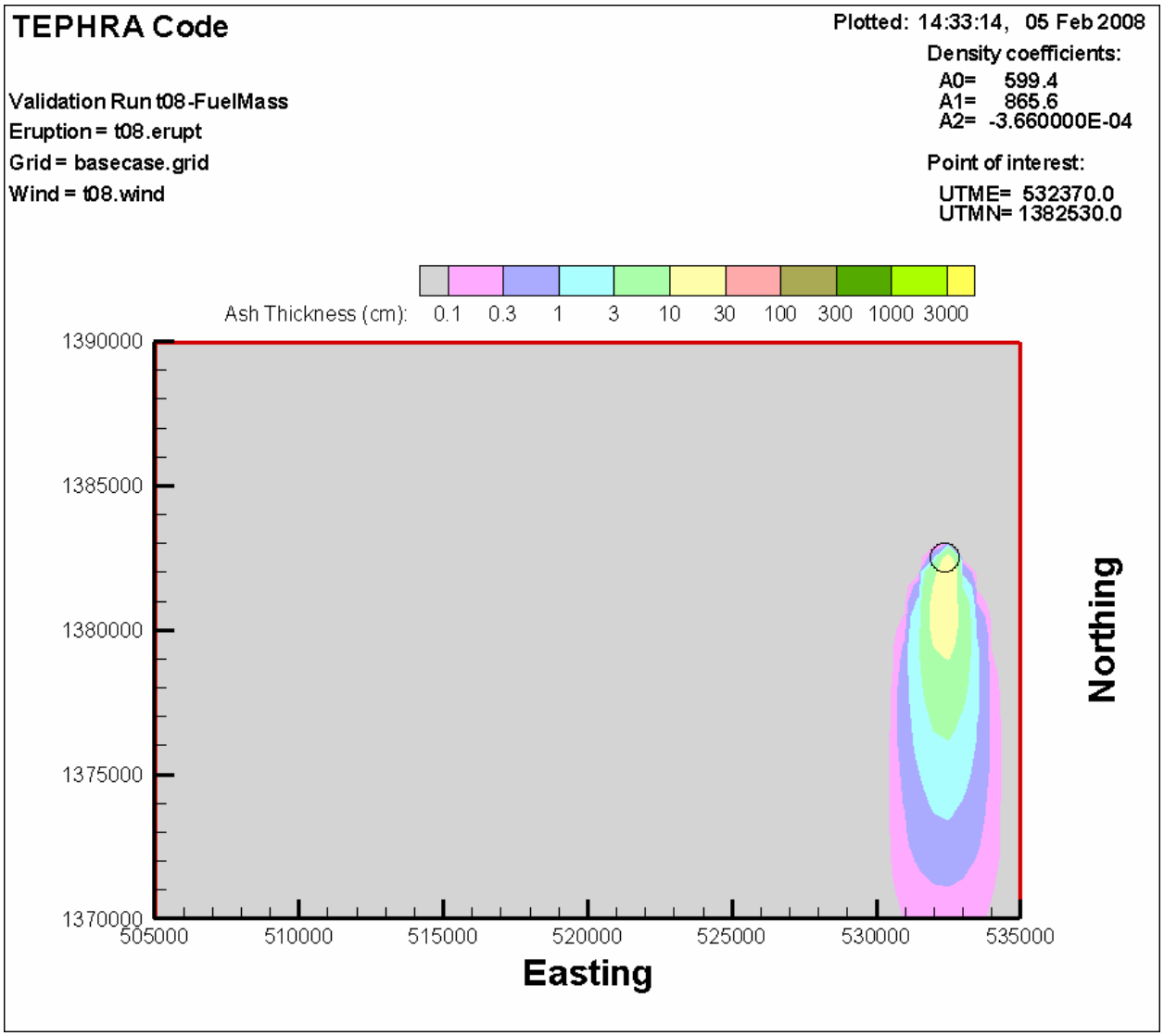


Figure 6.9-2. ***t08_ind_180.tif*** **{Total Erupted Fuel Mass = 9,000 kg [19,841 lb]}**

6.10 Test 9—Diffusion

Objective

This test is designed to show the effect of the diffusion coefficient value on the ash deposition pattern. Unlike previous tests that varied parameters specified in the eruption file, this and many of the following tests address parameters in the configuration file. The configuration file can only specify parameters for one eruption, whereas the eruption file can specify parameters for several eruptions. This means that tests of parameters in the configuration file require a separate TEPHRA run for each change in parameter value. The input files listed for this test contain two configuration files—one for each run considered. All other input files remain unchanged for the two runs. The wind velocity vectors are set to 0 m s^{-1} to present a simple circular deposition pattern that is used to compare the diffusion characteristics of the two eruptions.

Test Inputs

The diffusion coefficient is changed from 100 to 1,000 m^2 s^{-1} [1,076 ft^2 s^{-1} to 10,764 ft^2 s^{-1}] in 10 steps. Only two of the cases are shown below.

Table 6.10-1. TEPHRA Input File *t09_1.conf*

```
SEED                     6
DIFFUSION_COEFFICIENT  100.0
FALL_TIME_THRESHOLD   1080.0
LITHIC_DENSITY        2350.0
PUMICE_DENSITY        1100.0
COL_STEPS               50
PLUME_MODEL              0
PLUME_RATIO              0.001
PROB_MAP                 0
SURVIVOR                 0
ASH_ACCUM_THRESHOLD      0.0
PROB_THRESHOLD           0.0
MAX_ACCUMULATION         0
COMPLIMENT               0
WIND_INTERVAL          500.0
WIND_LEVELS               5
WIND_DAYS                1
WIND_COLUMNS             3
```

Table 6.10-2. TEPHRA Input File *t09_9.conf*	
SEED	6
DIFFUSION_COEFFICIENT	900.0
FALL_TIME_THRESHOLD	1080.0
LITHIC_DENSITY	2350.0
PUMICE_DENSITY	1100.0
COL_STEPS	50
PLUME_MODEL	0
PLUME_RATIO	0.001
PROB_MAP	0
SURVIVOR	0
ASH_ACCUM_THRESHOLD	0.0
PROB_THRESHOLD	0.0
MAX_ACCUMULATION	0
COMPLIMENT	0
WIND_INTERVAL	500.0
WIND_LEVELS	5
WIND_DAYS	1
WIND_COLUMNS	3

Table 6.10-3. TEPHRA Input File *basecase.erupt*
1382530 532370 1000000000 -5.00 5.00 0.50 1 0.5 0.0 2000.00000 0.5 1000 -2 -4 -3 0.1 100

Table 6.10-4. TEPHRA Input File *t09.wind*		
0.0	0.0	-100.0
500.0	0.0	-100.0
1000.0	0.0	-100.0
1500.0	0.0	-100.0
2000.0	0.0	-100.0

Table 6.10-5. *t2t.e* Postprocessor Input File *t09ind.t2t*

```
TEPHRA_OUTPUT_FILE
  't09.all'
!
HEIGHT_PER_GRID_POINT_FILE
  'basecase.height'
!
MODE(individual;cumulative)
  'individual'
!
COORDINATE_SYSTEM(rectangular;cylindrical)
  'rectangular'
!
EOLIAN_AREA_LOWER_LEFT(x,y)
  505000, 1370000
!
EOLIAN_AREA_UPPER_RIGHT(x,y)
  535000, 1390000
!
ERUPTION_RANGE(start,stop)
  1,10
!
ERUPTIONS_IN_FILE
  10
!
DENSITY_COEFFICIENTS
 599.4, 865.6, -3.66e-04
!
POINT_OF_INTEREST(UTM)
 532370.0, 1382530.0
!
! END
```

Test Procedure

The script file for this test was prepared for 10 individual TEPHRA runs, each with a unique diffusion value, and executed in subdirectory *t09-Diffusion.* The file is listed in Table 6.10-6.

Table 6.10-6. Test 09 Script File *t09.run*

```
      date > t09.time
mpirun -np 1 \
      ../../tephra \
      t09_1.conf     \
      basecase.erupt  \
      basecase.grid   \
      t09.wind        \
      t09_1.all > t09_1.cum
mpirun -np 1 \
      ../../tephra \
      t09_2.conf     \
      basecase.erupt  \
basecase.grid   \
```

Table 6.10-6. Test 09 Script File *t09.run* (continued)

```
      t09.wind        \
      t09_2.all > t09_2.cum
mpirun -np 1 \
      ../../tephra \
t09_3.conf     \
      basecase.erupt  \
      basecase.grid   \
      t09.wind        \
      t09_3.all > t09_3.cum
mpirun -np 1 \
      ../../tephra \
      t09_4.conf     \
      basecase.erupt  \
      basecase.grid   \
      t09.wind        \
      t09_4.all > t09_4.cum
mpirun -np 1 \
      ../../tephra \
      t09_5.conf     \
      basecase.erupt  \
      basecase.grid   \
      t09.wind        \
      t09_5.all > t09_5.cum
mpirun -np 1 \
      ../../tephra \
      t09_6.conf     \
      basecase.erupt  \
      basecase.grid   \
      t09.wind        \
      t09_6.all > t09_6.cum
mpirun -np 1 \
      ../../tephra \
      t09_7.conf     \
      basecase.erupt  \
      basecase.grid   \
      t09.wind        \
      t09_7.all > t09_7.cum
mpirun -np 1 \
      ../../tephra \
      t09_8.conf     \
      basecase.erupt  \
      basecase.grid   \
      t09.wind        \
      t09_8.all > t09_8.cum
mpirun -np 1 \
      ../../tephra \
      t09_9.conf     \
basecase.erupt  \
      basecase.grid   \
      t09.wind        \
      t09_9.all > t09_9.cum
mpirun -np 1 \
      ../../tephra \
      t09_10.conf     \
      basecase.erupt  \
```

Table 6.10-6. Test 09 Script File *t09.run* (continued)

```
     basecase.grid   \
t09.wind        \

     t09_10.all > t09_10.cum

date >> t09.timecat t09 1.all t09 2.all t09 3.all t09 4.all t09 5.all
t09_6.all t09_7.all t09_8.all t09_9.all t09_10.all >t09.all

cat  t09_1.cum  t09_2.cum  t09_3.cum  t09 4.cum  t09 5.cum  t09 6.cum
t09_7.cum t09_8.cum t09_9.cum t09_10.cum >t09.cum

../../tecplot/t2t/t2t.e <t09ind.t2t

mv t2t_ind*.tec t09ind.tec

../../tecplot/t2t/t2t.e <t09cum.t2t

mv t2t_cum*.tec t09cum.tec
```

Test Results

A larger diffusion coefficient is expected to produce a broader deposition pattern for the ash thickness. The circular deposition pattern in Figure 6.10-2 with a diffusion coefficient of 900 $m^2\ s^{-1}$ [9,688 $ft^2\ s^{-1}$] has a radial component about twice that of Figure 6.10-1 where the diffusion coefficient has a value of 100 $m^2\ s^{-1}$ [1,076 $ft^2\ s^{-1}$]. This is consistent with the expected results.

Test Rating

Pass

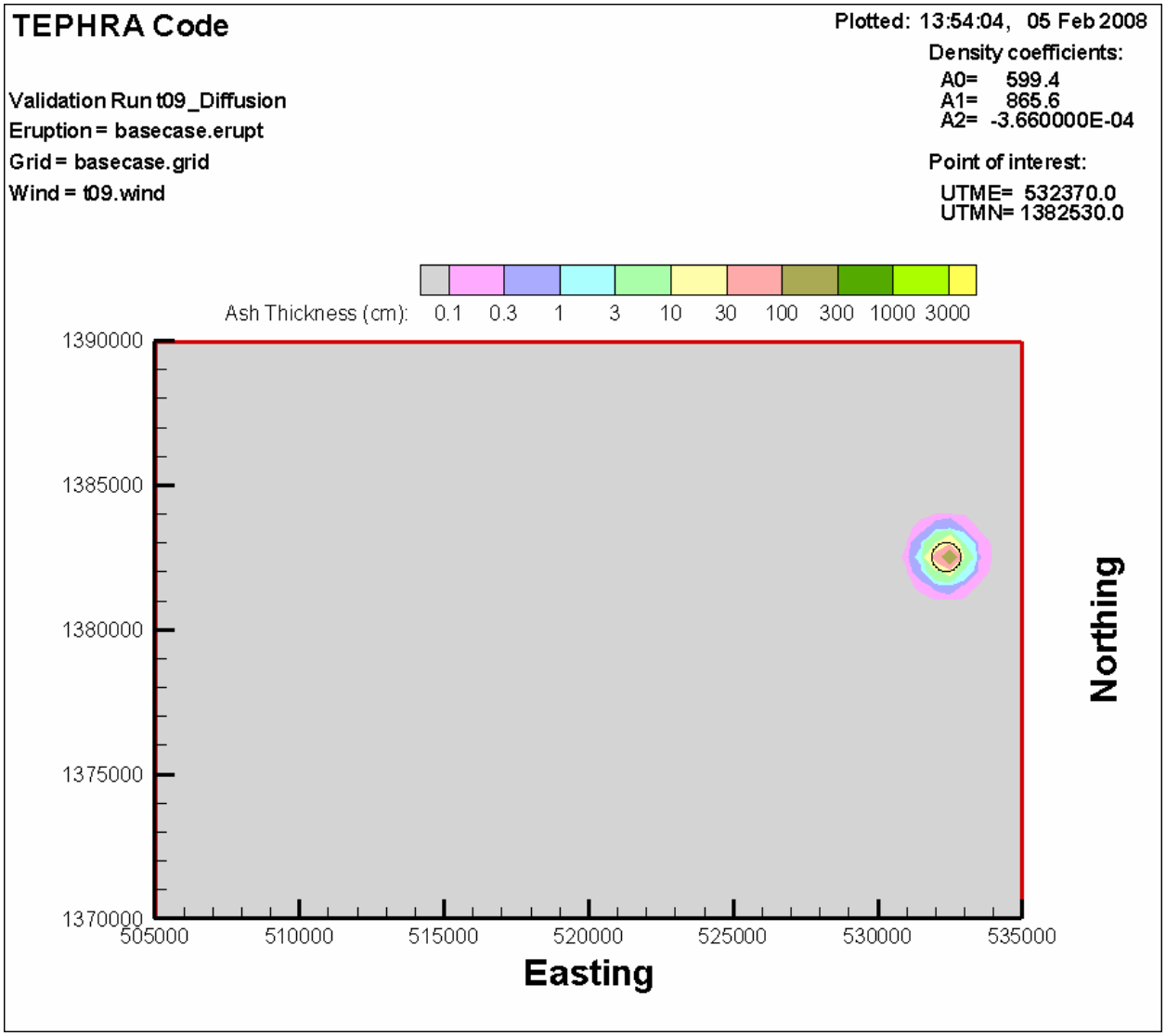


Figure 6.10-1. ***t09_ind_100.tif*** **{Diffusion Coefficient = 100 $m^2\ s^{-1}$ [1,076 $ft^2\ s^{-1}$]}**

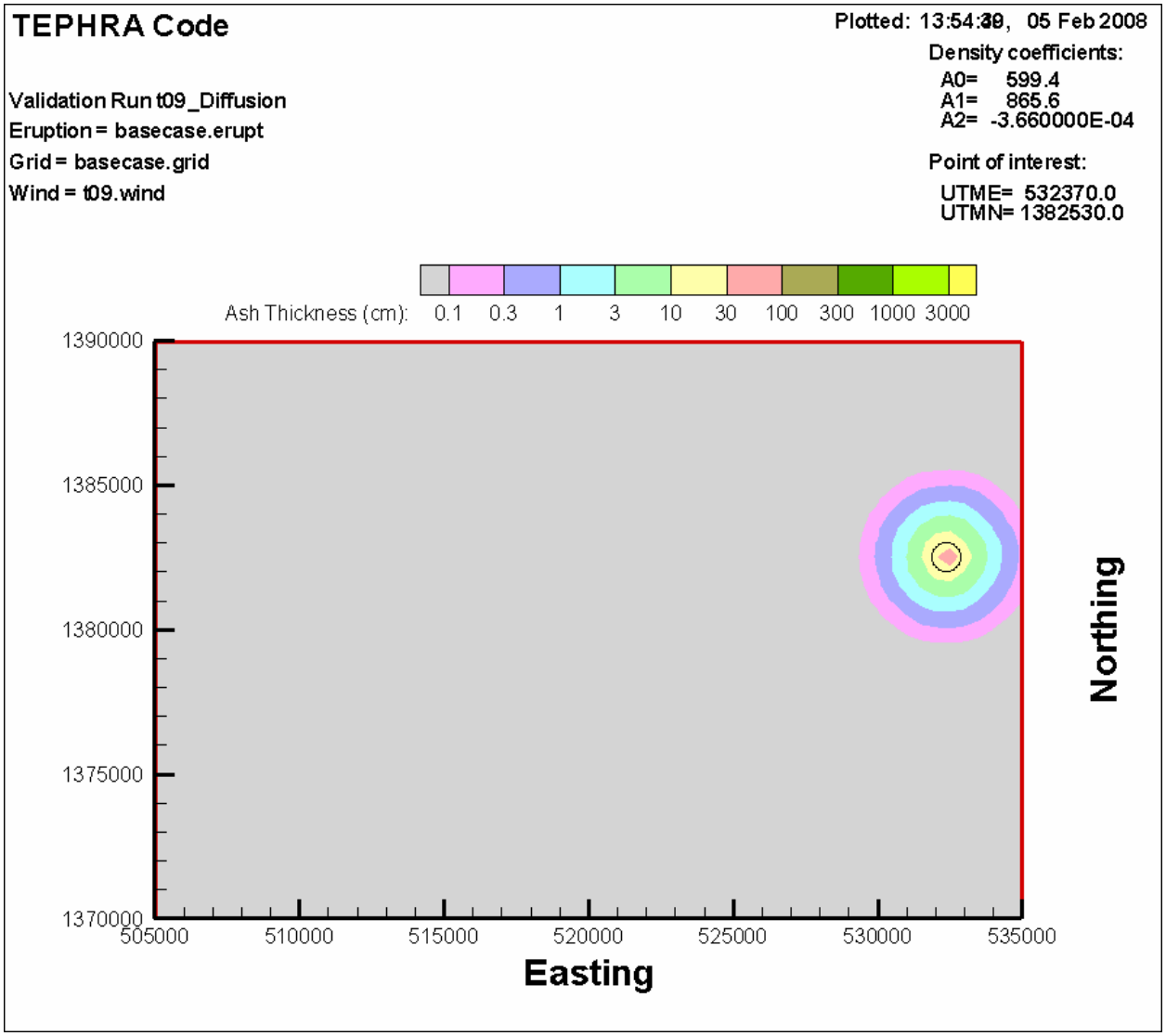


Figure 6.10-2. ***t09_ind_180.tif*** **{Diffusion Coefficient = 900 m^2 s^{-1} [9,688 ft^2 s^{-1}]}**

6.11 Test 10—Diffusion Threshold

Objective

This test is designed to show the effect of the diffusion threshold value on the ash deposition pattern. The diffusion threshold is used to select either an eddy diffusion model for smaller particles or a model using the diffusion coefficient when considering larger particles.

Test Inputs

The diffusion threshold was varied from 280 s to 2,080 s in 10 steps. The first and ninth steps are presented here.

Table 6.11-1. TEPHRA Input File *t10_1.conf*

```
SEED                      6
DIFFUSION_COEFFICIENT  400.0
FALL_TIME_THRESHOLD    280.0
LITHIC_DENSITY        2350.0
PUMICE_DENSITY        1100.0
COL_STEPS               50
PLUME_MODEL              0
PLUME_RATIO              0.001
PROB_MAP                 0
SURVIVOR                 0
ASH_ACCUM_THRESHOLD      0.0
PROB_THRESHOLD           0.0
MAX_ACCUMULATION         0
COMPLIMENT               0
WIND_INTERVAL          500.0
WIND_LEVELS               5
WIND_DAYS                1
WIND_COLUMNS             3
```

Table 6.11-2. TEPHRA Input File *t10_9.conf*

```
SEED                      6
DIFFUSION_COEFFICIENT  400.0
FALL_TIME_THRESHOLD   1880.0
LITHIC_DENSITY        2350.0
PUMICE_DENSITY        1100.0
COL_STEPS               50
PLUME_MODEL              0
PLUME_RATIO              0.001
PROB_MAP                 0
SURVIVOR                 0
ASH_ACCUM_THRESHOLD      0.0
PROB_THRESHOLD           0.0
MAX_ACCUMULATION         0
COMPLIMENT               0
WIND_INTERVAL          500.0
WIND_LEVELS               5
WIND_DAYS                1
WIND_COLUMNS             3
```

Table 6.11-3. TEPHRA Input File *basecase.erupt*

```
1382530 532370 1000000000 -5.00  5.00 0.50 1 0.5 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
```

Table 6.11-4. TEPHRA Input File *t10_1.wind*

```
   0.0  10.0 -100.0
 500.0  10.0 -100.0
1000.0  10.0 -100.0
1500.0  10.0 -100.0
2000.0  10.0 -100.0
```

Table 6.11-5. TEPHRA Input File *t10_9.wind*

```
   0.0  10.0 -180.0
 500.0  10.0 -180.0
1000.0  10.0 -180.0
1500.0  10.0 -180.0
2000.0  10.0 -180.0
```

Table 6.11-6. *t2t.e* Postprocessor Input File *t10ind.t2t*

```
! Input file for program t2t.f90
!
TECPLOT_TITLE
  'TEPHRA Code Validation Run t10_DiffusionThreshold'
!
LABEL_1
  ' Validation Run t10_DiffusionThreshold'
!
LABEL_2
  ' Eruption = basecase.erupt'
!
LABEL_3
  ' Grid = basecase.grid'
!
LABEL_4
  ' Wind = t10_*.wind'
!
TEPHRA_OUTPUT_FILE
  't10.all'
!
HEIGHT_PER_GRID_POINT_FILE
  'basecase.height'
!
MODE(individual;cumulative)
  'individual'
!
COORDINATE_SYSTEM(rectangular;cylindrical)
  'rectangular'
!
EOLIAN_AREA_LOWER_LEFT(x,y)
```

Table 6.11-6. *t2t.e* Postprocessor Input File *t10ind.t2t* (continued)

```
  505000, 1370000
!
EOLIAN_AREA_UPPER_RIGHT(x,y)
  535000, 1390000
!
ERUPTION_RANGE(start,stop)
  1,10
!
ERUPTIONS_IN_FILE
  10
!
DENSITY_COEFFICIENTS
 599.4, 865.6, -3.66e-04
!
POINT_OF_INTEREST(UTM)
 532370.0, 1382530.0
!
! END
```

Test Procedure

The script file for this test was run in subdirectory *t10-DiffusionThreshold* and is listed in Table 6.11-7.

Table 6.11-7. Test 10 Script File *t10.run*

```
date > t10.time
mpirun -np 1 \
../../tephra \
t10_1.conf     \
basecase.erupt  \
basecase.grid   \
t10_1.wind        \
t10_1.all > t10_1.cum
mpirun -np 1 \
../../tephra \
t10_2.conf     \
basecase.erupt  \
basecase.grid   \
t10_2.wind        \
t10_2.all > t10_2.cum
mpirun -np 1 \
../../tephra \
t10_3.conf     \
basecase.erupt  \
basecase.grid   \
t10_3.wind        \
      t10_3.all > t10_3.cum
mpirun -np 1 \
      ../../tephra \
      t10_4.conf     \
      basecase.erupt  \
      basecase.grid   \
      t10_4.wind        \
      t10_4.all > t10_4.cum
```

Table 6.11-7. Test 10 Script File *t10.run* (continued)

```
mpirun -np 1 \
      ../../tephra \t10_5.conf     \
      basecase.erupt  \
      basecase.grid   \
      t10_5.wind        \
      t10_5.all > t10_5.cum
mpirun -np 1 \
      ../../tephra \
      t10_6.conf     \
      basecase.erupt  \
      basecase.grid   \
      t10_6.wind        \
      t10_6.all > t10_6.cum
mpirun -np 1 \
      ../../tephra \
      t10_7.conf     \
      basecase.erupt  \
      basecase.grid   \
      t10_7.wind        \
      t10_7.all > t10_7.cum
mpirun -np 1 \
      ../../tephra \
      t10_8.conf     \
      basecase.erupt  \
      basecase.grid   \
      t10_8.wind        \
      t10_8.all > t10_8.cum
mpirun -np 1 \
      ../../tephra \
      t10_9.conf     \
      basecase.erupt  \
      basecase.grid   \
      t10_9.wind        \
      t10_9.all > t10_9.cum
mpirun -np 1 \
      ../../tephra \
      t10_10.conf     \
      basecase.erupt  \
      basecase.grid   \
      t10_10.wind        \
      t10_10.all > t10_10.cum
date >> t10.time
cat  t10_1.all  t10_2.all  t10_3.all  t10_4.all  t10_5.all  t10_6.all
t10_7.all t10_8.all t10_9.all t10_10.all >t10.all
cat  t10_1.cum  t10_2.cum  t10_3.cum  t10_4.cum  t10_5.cum  t10_6.cum
t10_7.cum t10_8.cum t10_9.cum t10_10.cum >t10.cum
../../tecplot/t2t/t2t.e <t10ind.t2t
mv t2t_ind*.tec t10ind.tec
../../tecplot/t2t/t2t.e <t10cum.t2t
mv t2t_cum*.tec t10cum.tec
```

Test Results

The effect of two diffusion models can be seen in Figure 6.11-1, where at a radial distance of about 3.5 km [2.2 mi] from the vent, a slight inflection point is seen in the contour edges. This is most easily seen in the 1-cm [0.4-in] thickness contour. The shorter fall time particles deposited close to the vent show a more narrow diffusion pattern, while particles with larger fall times that were deposited further from the vent show a broader diffusion pattern. This is consistent with the dual diffusion model implemented in the TEPHRA code. The inflection point is absent from Figure 6.11-2, where the threshold is larger than the fall time for even the fine particles and a single diffusion model is used for all particles.

Test Rating

Pass

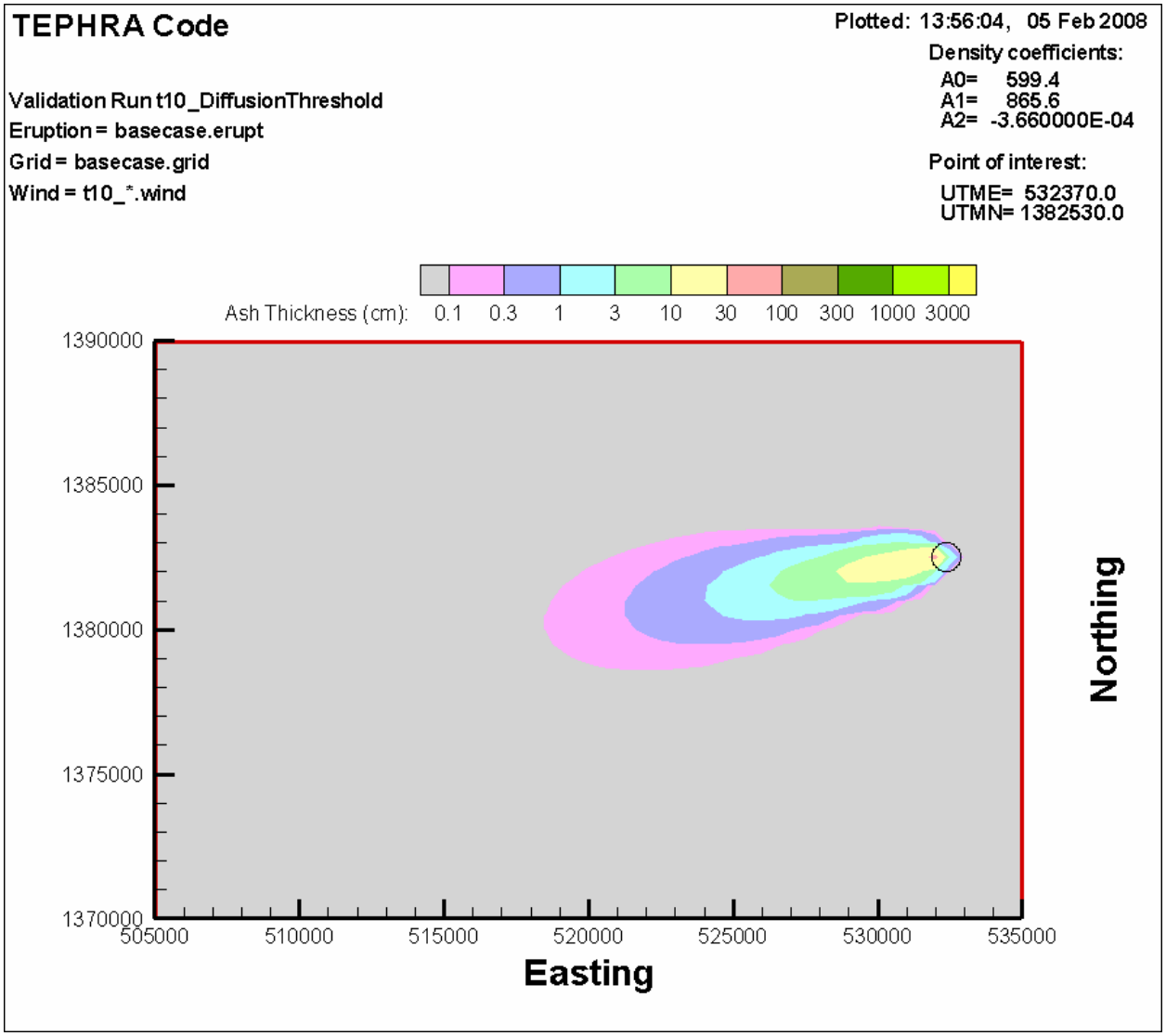


Figure 6.11-1. ***t10_ind_100.tif*** **[Diffusion Threshold = 280 s]**

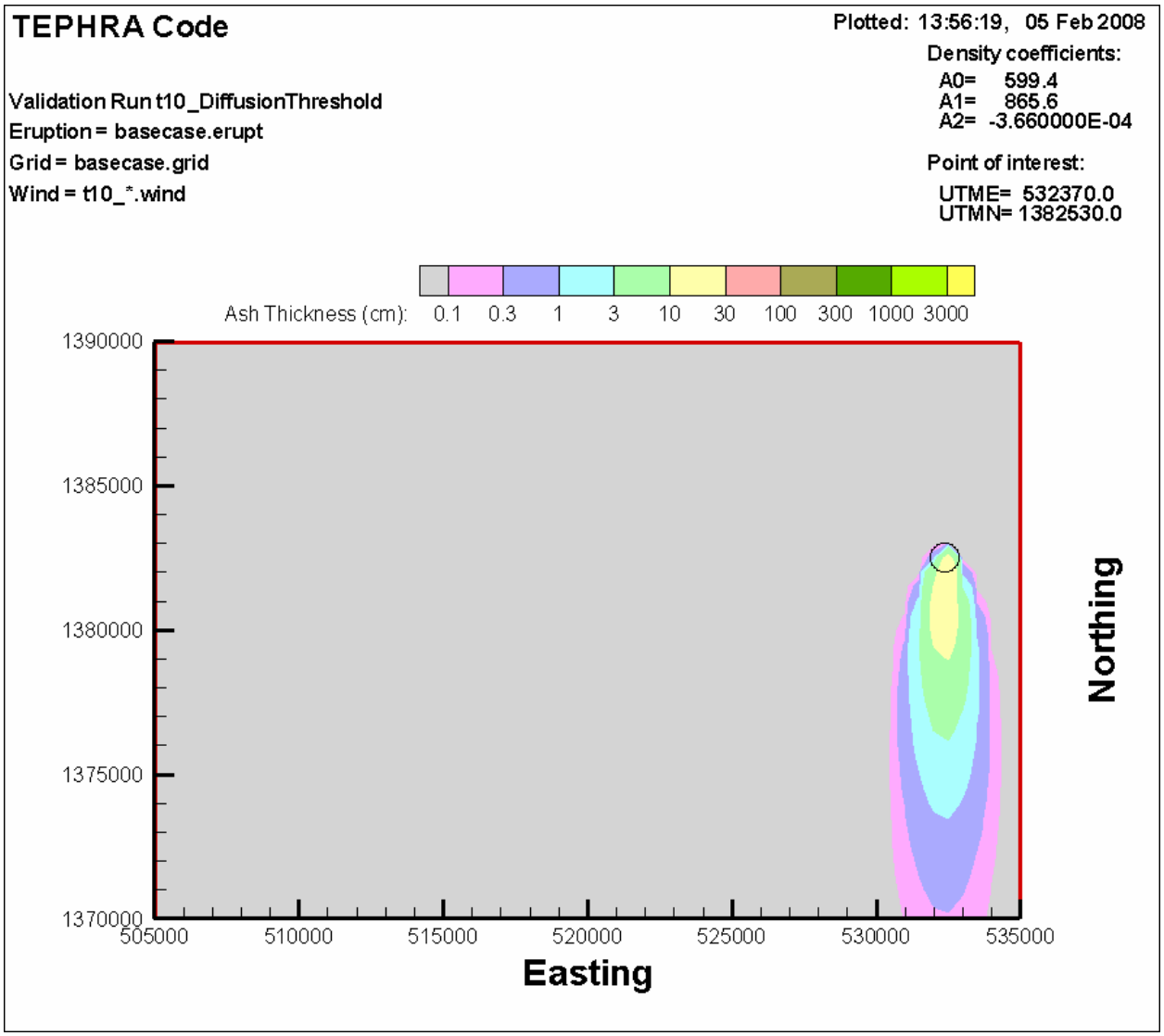


Figure 6.11-2. ***t10_ind_180.tif*** **[Diffusion Threshold = 1,880 s]**

6.12 Test 11—Plume Ratio

Objective

This test is designed to show the effect of the plume ratio value on the ash deposition pattern. The plume ratio is the ratio of the elevation of the bottom of the plume to the elevation of the top of the plume. Larger plume ratios are expected to exhibit a more distal concentration of ash in a uniform wind velocity profile and a fixed column height.

Test Inputs

Table 6.12-1. TEPHRA Input File *t11_2.conf*

```
SEED                      6
DIFFUSION_COEFFICIENT  400.0
FALL_TIME_THRESHOLD   1080.0
LITHIC_DENSITY        2350.0
PUMICE_DENSITY        1100.0
COL_STEPS               50
PLUME_MODEL              0
PLUME_RATIO              0.201
PROB_MAP                 0
SURVIVOR                 0
ASH_ACCUM_THRESHOLD      0.0
PROB_THRESHOLD           0.0
MAX_ACCUMULATION         0
COMPLIMENT               0
WIND_INTERVAL          500.0
WIND_LEVELS               5
WIND_DAYS                1
WIND_COLUMNS             3
```

Table 6.12-2. TEPHRA Input File *t11_8.conf*

```
SEED                      6
DIFFUSION_COEFFICIENT  400.0
FALL_TIME_THRESHOLD   1080.0
LITHIC_DENSITY        2350.0
PUMICE_DENSITY        1100.0
COL_STEPS               50
PLUME_MODEL              0
PLUME_RATIO              0.801
PROB_MAP                 0
SURVIVOR                 0
ASH_ACCUM_THRESHOLD      0.0
PROB_THRESHOLD           0.0
MAX_ACCUMULATION         0
COMPLIMENT               0
WIND_INTERVAL          500.0
WIND_LEVELS               5
WIND_DAYS                1
WIND_COLUMNS             3
```

Table 6.12-3. TEPHRA Input File *basecase.erupt*

```
1382530 532370 1000000000 -5.00  5.00 0.50 1 0.5 0.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
```

Table 6.12-4. TEPHRA Input File *t11_2.wind*

```
0.0  10.0 -110.0
 500.0  10.0 -110.0
1000.0  10.0 -110.0
1500.0  10.0 -110.0
2000.0  10.0 -110.0
```

Table 6.12-5. TEPHRA Input File *t11_8.wind*

```
   0.0  10.0 -170.0
 500.0  10.0 -170.0
1000.0  10.0 -170.0
1500.0  10.0 -170.0
2000.0  10.0 -170.0
```

Table 6.12-6. *t2t.e* Postprocessor Input File *t11ind.t2t*

```
! Input file for program t2t.f90
!
TECPLOT_TITLE
  'TEPHRA Code Validation Run t11_PlumeRatio'
!
LABEL_1
  ' Validation Run t11_PlumeRatio'
!
LABEL_2
  ' Eruption = basecase.erupt'
!
LABEL_3
  ' Grid = basecase.grid'
!
LABEL_4
  ' Wind = t11_*.wind'
!
TEPHRA_OUTPUT_FILE
  't11.all'
!
HEIGHT_PER_GRID_POINT_FILE
  'basecase.height'
!
MODE(individual;cumulative)
  'individual'
!
COORDINATE_SYSTEM(rectangular;cylindrical)
  'rectangular'
!
EOLIAN_AREA_LOWER_LEFT(x,y)
  505000, 1370000
!
EOLIAN_AREA_UPPER_RIGHT(x,y)
  535000, 1390000
!
ERUPTION_RANGE(start,stop)
  1,10
!
```

Table 6.12-6. *t2t.e* Postprocessor Input File *t11ind.t2t* (continued)

```
ERUPTIONS_IN_FILE
  10
!
DENSITY_COEFFICIENTS
 599.4, 865.6, -3.66e-04
!
POINT_OF_INTEREST(UTM)
 532370.0, 1382530.0
!
! END
```

Test Procedure

The plume ratio parameter is only used for plume model 0, so this test must set the PLUME_MODEL parameter to 0 in all configuration files used. The plume ratio is varied from .101 to .999 in 10 steps in the configuration file set used for this test. Only 2 of the 10 TEPHRA runs are discussed here. The script file for this test was run in subdirectory *t11-PlumeRatio* and is listed in Table 6.12-7.

Table 6.12-7. Test 11 Script File *t11.run*

```
date > t11.time
mpirun -np 1 \
      ../../tephra \
      t11_1.conf     \
      basecase.erupt  \
      basecase.grid   \
      t11_1.wind        \
      t11_1.all > t11_1.cum
mpirun -np 1 \
      ../../tephra \
      t11_2.conf     \
      basecase.erupt  \
      basecase.grid   \
      t11_2.wind        \
      t11_2.all > t11_2.cum
mpirun -np 1 \
      ../../tephra \
      t11_3.conf     \
      basecase.erupt  \
      basecase.grid   \
      t11_3.wind        \
t11_3.all > t11_3.cum
mpirun -np 1 \
      ../../tephra \
      t11_4.conf     \
      basecase.erupt  \
      basecase.grid   \
      t11_4.wind        \
      t11_4.all > t11_4.cum
mpirun -np 1 \
      ../../tephra \
t11_5.conf     \
      basecase.erupt  \
      basecase.grid   \
```

Table 6.12-7. Test 11 Script File *t11.run* (continued)

```
      t11_5.wind        \
      t11_5.all > t11_5.cum
mpirun -np 1 \
      ../../tephra \
      t11_6.conf     \
      basecase.erupt  \
      basecase.grid   \
      t11_6.wind        \
      t11_6.all > t11_6.cum
mpirun -np 1 \
      ../../tephra \
      t11_7.conf     \
      basecase.erupt  \
      basecase.grid   \
      t11_7.wind        \
      t11_7.all > t11_7.cum
mpirun -np 1 \
      ../../tephra \
      t11_8.conf     \
      basecase.erupt  \
      basecase.grid   \
      t11_8.wind        \
      t11_8.all > t11_8.cum
mpirun -np 1 \
      ../../tephra \
      t11_9.conf     \
      basecase.erupt  \
      basecase.grid   \
      t11_9.wind        \
      t11_9.all > t11_9.cum
mpirun -np 1 \
      ../../tephra \
      t11_10.conf     \
      basecase.erupt  \
      basecase.grid   \
      t11_10.wind        \
      t11_10.all > t11_10.cum
date >> t11.time
cat   t11 1.all   t11 2.all   t11 3.all   t11 4.all   t11 5.all   t11 6.all
t11_7.all t11_8.all t11_9.all t11_10.all >t11.all
cat   t11 1.cum   t11 2.cum   t11 3.cum   t1t11.cum   t11 5.cum   t11 6.cum
t11_7.cum t11_8.cum t11_9.cum t11_10.cum >t11.cum
../../tecplot/t2t/t2t.e <t11ind.t2t
mv t2t_ind*.tec t11ind.tec
../../tecplot/t2t/t2t.e <t11cum.t2t
mv t2t_cum*.tec t11cum.tec
```

Test Results

The ash deposition contours of Figure 6.12-2 are farther from the vent than those of Figure 6.12-1, indicating that the larger plume ratio produces more distal deposits of ash. This is consistent with plume model 0 implemented in the TEPHRA code.

Test Rating

Pass

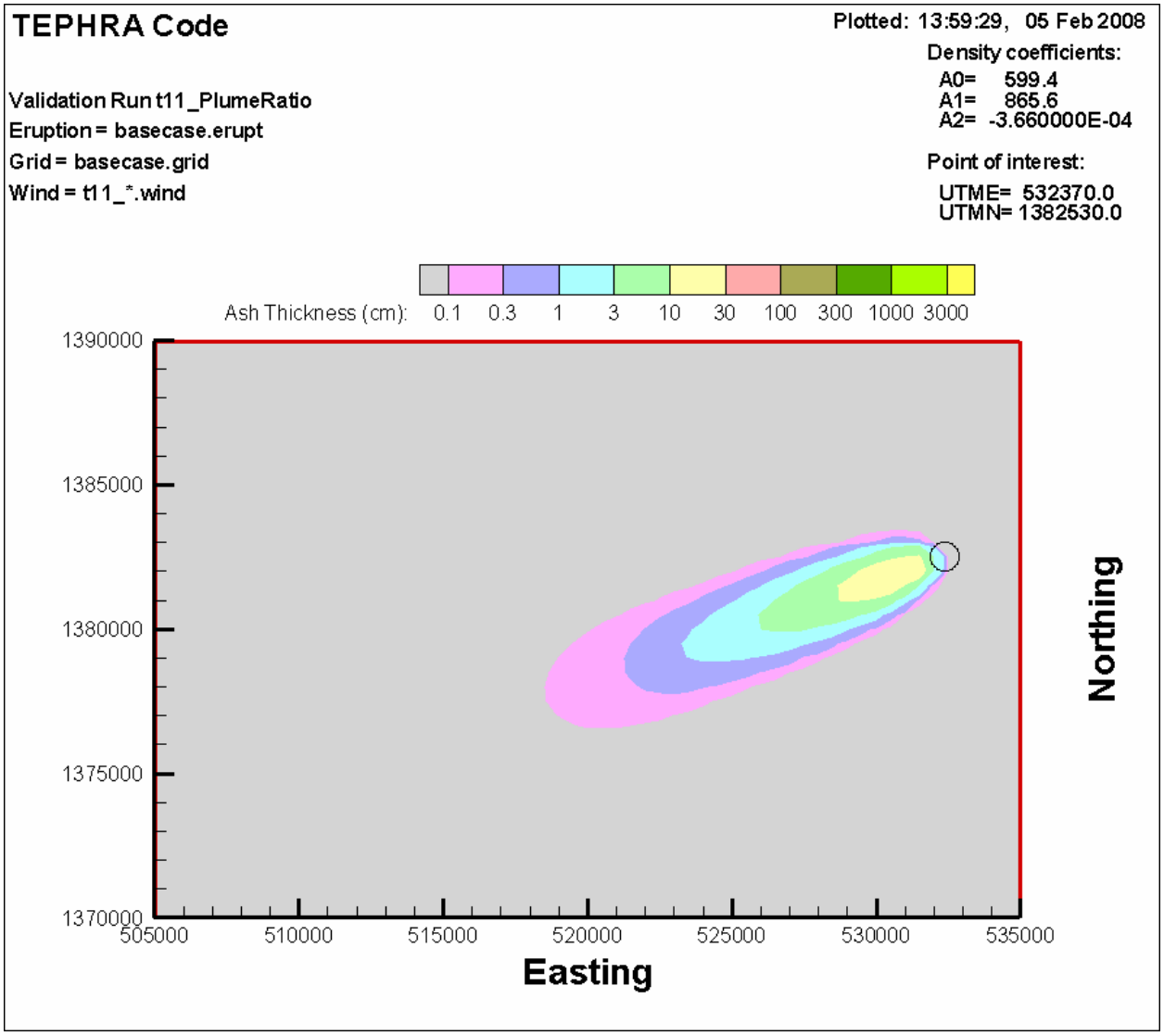


Figure 6.12-1. ***t11_ind_110.tif*** **[Plume Ratio = 0.201]**

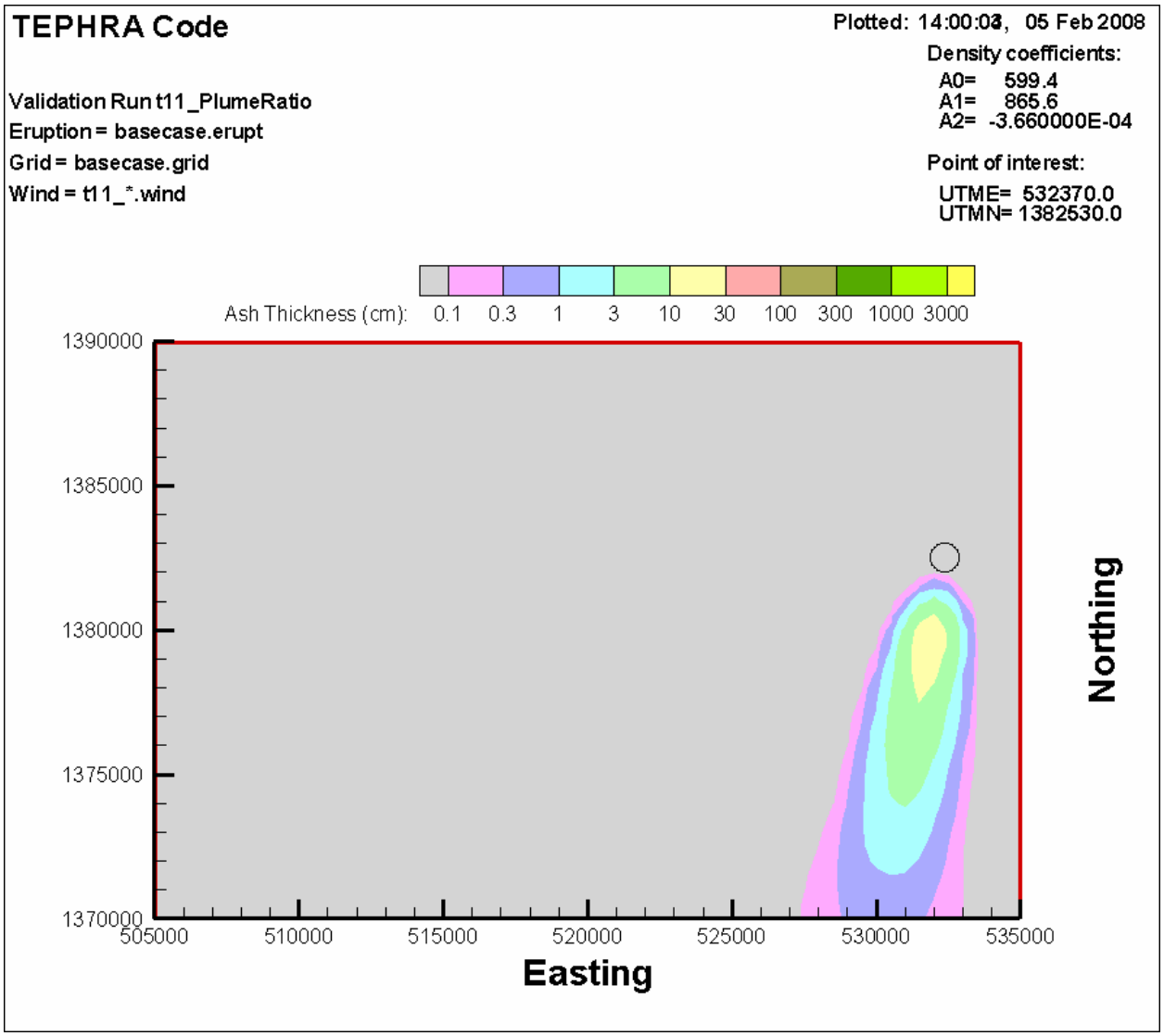


Figure 6.12-2. ***t11_ind_170.tif*** **[Plume Ratio = 0.801]**

6.13 Test 12—Plume Model

Objective

This test is designed to show that the plume model parameter selects different plume models of the TEPHRA code. The only parameter changed is the plume model selector. The plume ratio is 0.001 and beta is 10 for both cases.

Test Inputs

Table 6.13-1. TEPHRA Input File *t12_0.conf*

```
SEED                      6
DIFFUSION_COEFFICIENT  400.0
FALL_TIME_THRESHOLD   1080.0
LITHIC_DENSITY        2350.0
PUMICE_DENSITY        1100.0
COL_STEPS               50
PLUME_MODEL              1
PLUME_RATIO              0.001
PROB_MAP                 0
SURVIVOR                 0
ASH_ACCUM_THRESHOLD      0.0
PROB_THRESHOLD           0.0
MAX_ACCUMULATION         0
COMPLIMENT               0
WIND_INTERVAL          500.0
WIND_LEVELS              5
WIND_DAYS                1
WIND_COLUMNS             3
```

Table 6.13-2. TEPHRA Input File *t12_1.conf*

```
SEED                      6
DIFFUSION_COEFFICIENT  400.0
FALL_TIME_THRESHOLD   1080.0
LITHIC_DENSITY        2350.0
PUMICE_DENSITY        1100.0
COL_STEPS               50
PLUME_MODEL              1
PLUME_RATIO              0.001
PROB_MAP                 0
SURVIVOR                 0
ASH_ACCUM_THRESHOLD      0.0
PROB_THRESHOLD           0.0
MAX_ACCUMULATION         0
COMPLIMENT               0
WIND_INTERVAL          500.0
WIND_LEVELS              5
WIND_DAYS                1
WIND_COLUMNS             3
```

Table 6.13-3. TEPHRA Input File *t12.erupt*

```
1382530 532370 1000000000 -5.00  5.00 0.50 1 0.5 0.0 2000.00000 10. 1000  -2 -4 -3 0.1 100
```

Table 6.13-4. TEPHRA Input File *t12.wind*

```
   0.0  10.0 -100.0
 500.0  10.0 -100.0
1000.0  10.0 -100.0
1500.0  10.0 -100.0
2000.0  10.0 -100.0
```

Table 6.13-5. *t2t.e* Postprocessor Input File *t12.t2t*

```
! Input file for program t2t.f90
!
TECPLOT_TITLE
  'TEPHRA Code Validation Run t12_1-PlumeModel'
!
LABEL_1
  ' Validation Run t12_1-PlumeModel'
!
LABEL_2
  ' Eruption = t12.erupt'
!
LABEL_3
  ' Grid = basecase.grid'
!
LABEL_4
  ' Wind = t12.wind'
!
TEPHRA_OUTPUT_FILE
  't12_1.all'
!
HEIGHT_PER_GRID_POINT_FILE
  'basecase.height'
!
MODE(individual;cumulative)
  'individual'
!
COORDINATE_SYSTEM(rectangular;cylindrical)
  'rectangular'
!
EOLIAN_AREA_LOWER_LEFT(x,y)
  505000, 1370000
!
EOLIAN_AREA_UPPER_RIGHT(x,y)
  535000, 1390000
!
ERUPTION_RANGE(start,stop)
  1,1
!
ERUPTIONS_IN_FILE
  1
!
DENSITY_COEFFICIENTS
 599.4, 865.6, -3.66e-04
!
POINT_OF_INTEREST(UTM)
 532370.0, 1382530.0
!
! END
```

Test Procedure

The plume ratio is set to 0.001 for both configuration files. This will present a uniform distribution of particles throughout the column when model 0 is selected. The beta parameter is set to 10 in the eruption file. This will model a plume with more particles near its top. If the plume models are selected correctly, the ash deposition patterns should be noticeably different. The script file for this test is run in subdirectory *t12-PlumeModel* and is listed in Table 6.13-6.

Table 6.13-6. Test 12 Script File *t12.run*

```
date > t12.time
mpirun -np 1 \
      ../../tephra \
      t12_0.conf     \
      t12.erupt  \
      basecase.grid   \
      t12.wind        \
      t12_0.all > t12_0.cum
mpirun -np 1 \
      ../../tephra \
      t12_1.conf     \
      t12.erupt  \
      basecase.grid   \
      t12.wind        \
      t12_1.all > t12_1.cum
date >> t12.time
../../tecplot/t2t/t2t.e <t12_0.t2t
mv t2t_ind*.tec t12_0.tec
../../tecplot/t2t/t2t.e <t12_1.t2t
mv t2t_ind*.tec t12_1.tec
```

Test Results

The ash deposition contours in Figure 6.13-1 are closer to the vent than those of Figure 6.13-2. This indicates that a different model was used for the two cases. In addition, the isopachs in Figure 6.13-2 are further from the vent than those of Figure 6.13-1, indicating that the beta parameter was used for that display. This is consistent with the plume models implemented in the TEPHRA code.

Test Rating

Pass

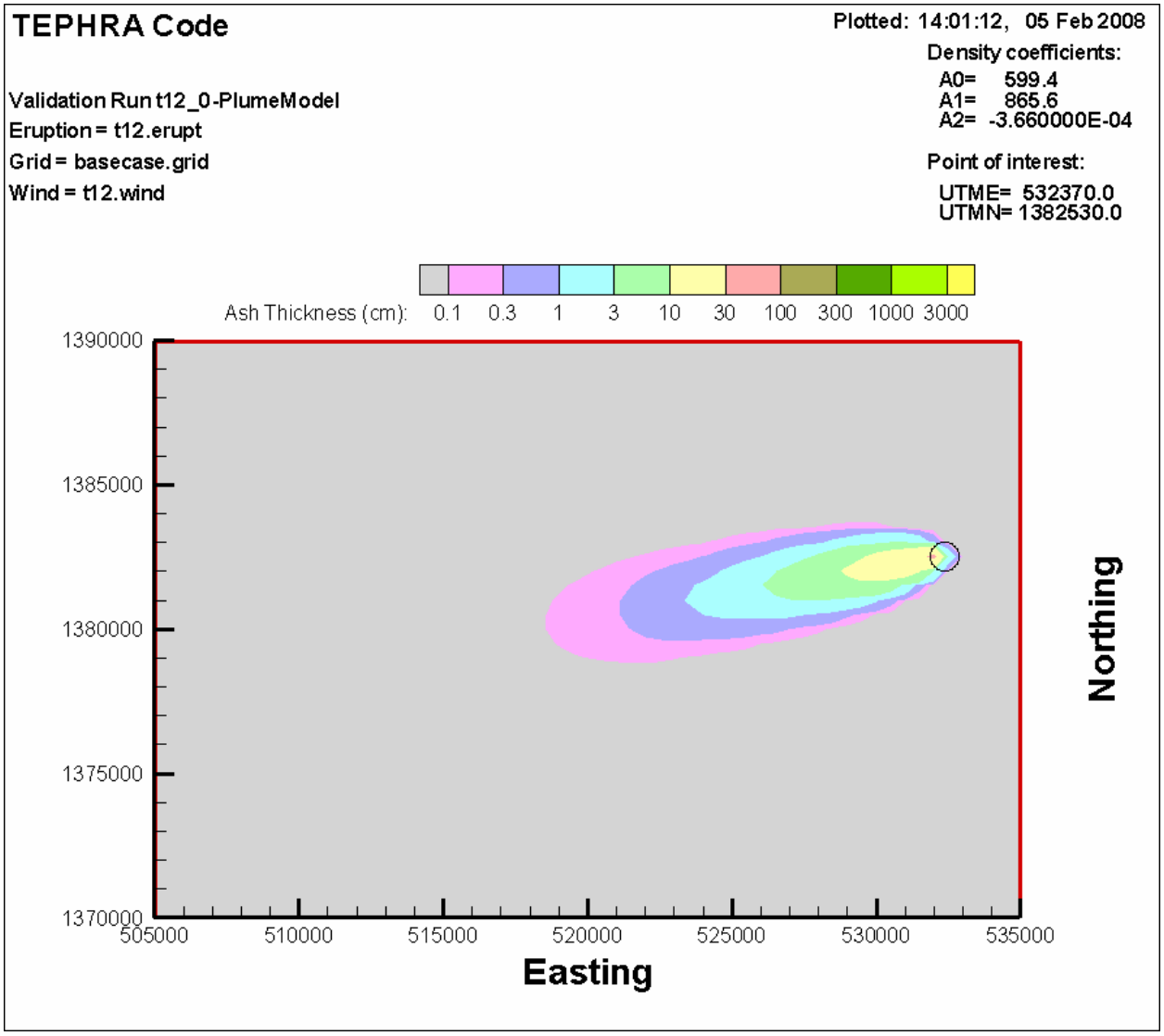


Figure 6.13-1. *t12_0.tif* [Plume Model = 0]

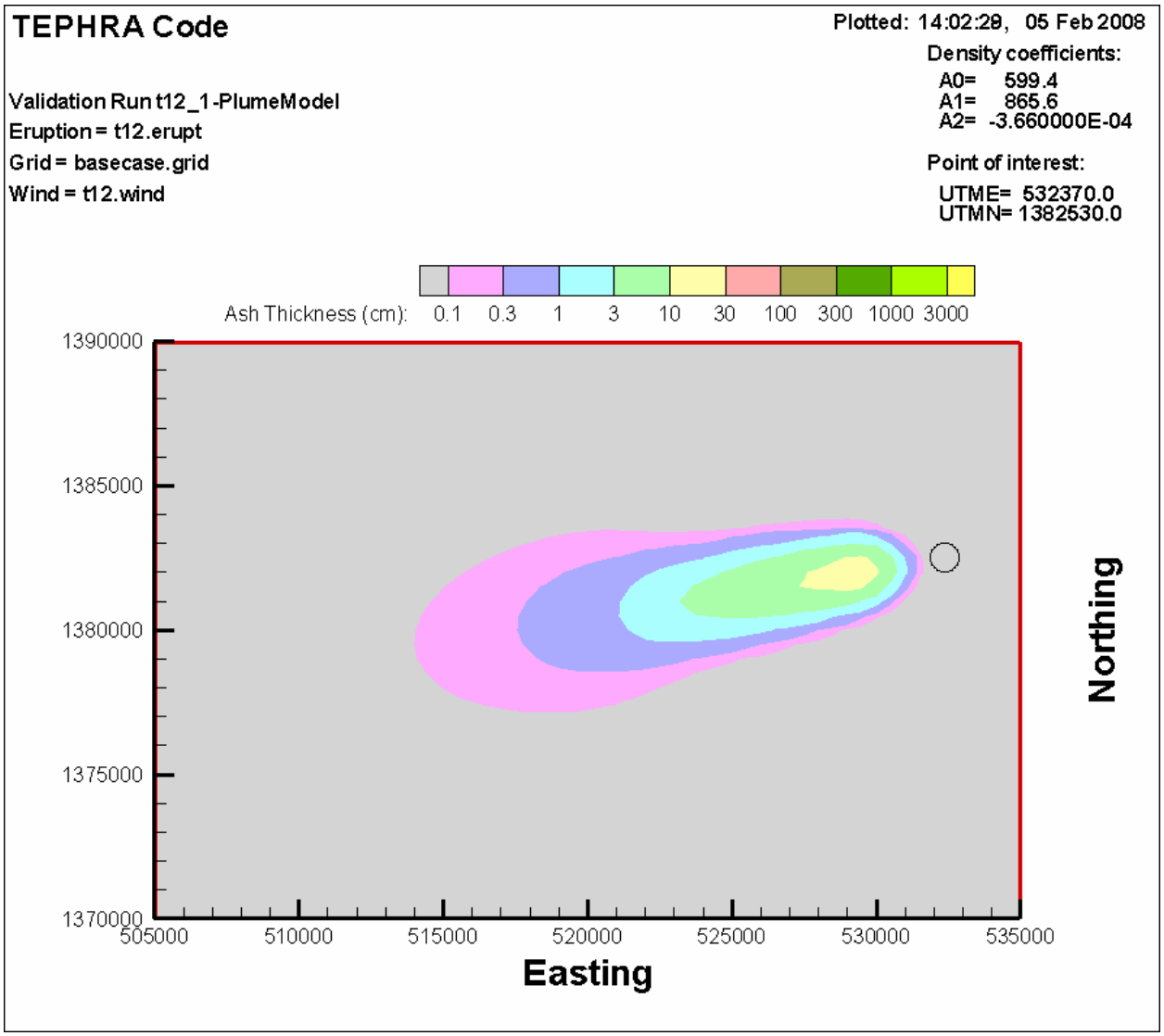


Figure 6.13-2. *t12_1.tif* [Plume Model = 1]

6.14 Test 13—Column Beta

Objective

This test is designed to show the effects of the beta parameter for plume model 1. Beta affects the vertical distribution of particles within the eruption column and helps determine where particles exit the column. As beta becomes larger, particle distribution becomes skewed toward the top of the eruption column. Therefore, beta determines how high most particles will travel before exiting the eruption column. Previous sensitivity results for the column beta parameter were performed using a different theoretical model for tephra dispersal and showed minor variations in deposit thickness over a range of distances (Hill, et al., 1998). Because a similar, relatively low eruption column height is used in this test, minor variations in deposit thickness are expected.

Test Inputs

Table 6.14-1. TEPHRA Input File *t13.conf*

```
SEED                      6
DIFFUSION_COEFFICIENT  400.0
FALL_TIME_THRESHOLD   1080.0
LITHIC_DENSITY        2350.0
PUMICE_DENSITY        1100.0
COL_STEPS               50
PLUME_MODEL              1
PLUME_RATIO              0.001
PROB_MAP                 0
SURVIVOR                 0
ASH_ACCUM_THRESHOLD      0.0
PROB_THRESHOLD           0.0
MAX_ACCUMULATION         0
COMPLIMENT               0
WIND_INTERVAL          500.0
WIND_LEVELS               5
WIND_DAYS                7
WIND_COLUMNS             3
```

Table 6.14-2. TEPHRA Input File *t13.erupt*

```
1382530 532370 1000000000 -5.00  5.00 0.50 1 0.5 5.0 2000.00000  0.5 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00 0.50 1 0.5 5.0 2000.00000  1.0 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00 0.50 1 0.5 5.0 2000.00000  2.0 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00 0.50 1 0.5 5.0 2000.00000  2.3 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00 0.50 1 0.5 5.0 2000.00000  3.0 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00 0.50 1 0.5 5.0 2000.00000  4.0 1000  -2 -4 -3 0.1 100
1382530 532370 1000000000 -5.00  5.00 0.50 1 0.5 5.0 2000.00000  6.0 1000  -2 -4 -3 0.1 100
```

Table 6.14-3. TEPHRA Input File *t13.wind*

```
1000.0  10.0 -100.0
1500.0  10.0 -100.0
2000.0  10.0 -100.0
   0.0  10.0 -100.0
 500.0  10.0 -100.0
1000.0  10.0 -100.0
1500.0  10.0 -100.0
2000.0  10.0 -100.0
   0.0  10.0 -100.0
 500.0  10.0 -100.0
1000.0  10.0 -100.0
1500.0  10.0 -100.0
2000.0  10.0 -100.0
   0.0  10.0 -100.0
 500.0  10.0 -100.0
1000.0  10.0 -100.0
1500.0  10.0 -100.0
2000.0  10.0 -100.0
   0.0  10.0 -100.0
 500.0  10.0 -100.0
1000.0  10.0 -100.0
1500.0  10.0 -100.0
2000.0  10.0 -100.0
   0.0  10.0 -100.0
 500.0  10.0 -100.0
1000.0  10.0 -100.0
1500.0  10.0 -100.0
2000.0  10.0 -100.0
```

Table 6.14-4. *t2t.e* Postprocessor Input File *t13ind.t2t*

```
! Input file for program t2t.f90
!
TECPLOT_TITLE
  'TEPHRA Code Validation Run t13-ColumnBeta'
!
LABEL_1
  ' Validation Run t13-ColumnBeta'
!
LABEL_2
  ' Eruption = t13.erupt'
!
LABEL_3
  ' Grid = basecase.grid'
!
LABEL_4
  ' Wind = t13.wind'
!
TEPHRA_OUTPUT_FILE
  't13.all'
!
HEIGHT_PER_GRID_POINT_FILE
  'basecase.height'
!
MODE(individual;cumulative)
```

Table 6.14-4. *t2t.e* Postprocessor Input File *t13ind.t2t* (continued)

```
  'individual'
!
COORDINATE_SYSTEM(rectangular;cylindrical)
  'rectangular'
!
EOLIAN_AREA_LOWER_LEFT(x,y)
  505000, 1370000
!
EOLIAN_AREA_UPPER_RIGHT(x,y)
  535000, 1390000
!
ERUPTION_RANGE(start,stop)
  1,7
!
ERUPTIONS_IN_FILE
  7
!
DENSITY_COEFFICIENTS
 599.4,  865.6,  -3.66e-4
!
POINT_OF_INTEREST(UTM)
 532370.0, 1382530.0
!
! END
```

Test Procedure

The script file for this test was run in subdirectory *t13-ColumnBeta* and is listed in Table 6.14-5.

Table 6.14-5. Test 13 Script File *t13.run*

```
date > t13.time
mpirun -np 4 \
      ../../tephra \
      t13.conf     \
      t13.erupt  \
      basecase.grid   \
      t13.wind        \
      t13.all > t13.cum
date >> t13.time
../../tecplot/t2t/t2t.e <t13ind.t2t
mv t2t_ind*.tec t13ind.tec
../../tecplot/t2t/t2t.e <t13cum.t2t
mv t2t_cum*.tec t13cum.tec
```

Test Results

Overall, the calculated deposits are very similar for the seven values of the column beta parameter. Negligible differences are present in the distal and medial regions of the deposit. Noticeable differences, however, are localized to within about 2 km [1.2 mi] from the vent. Because these near-vent differences represent minor variations when the entire deposit is considered, the calculated results are found to be largely insensitive to the column beta parameter.

Test Rating

Pass

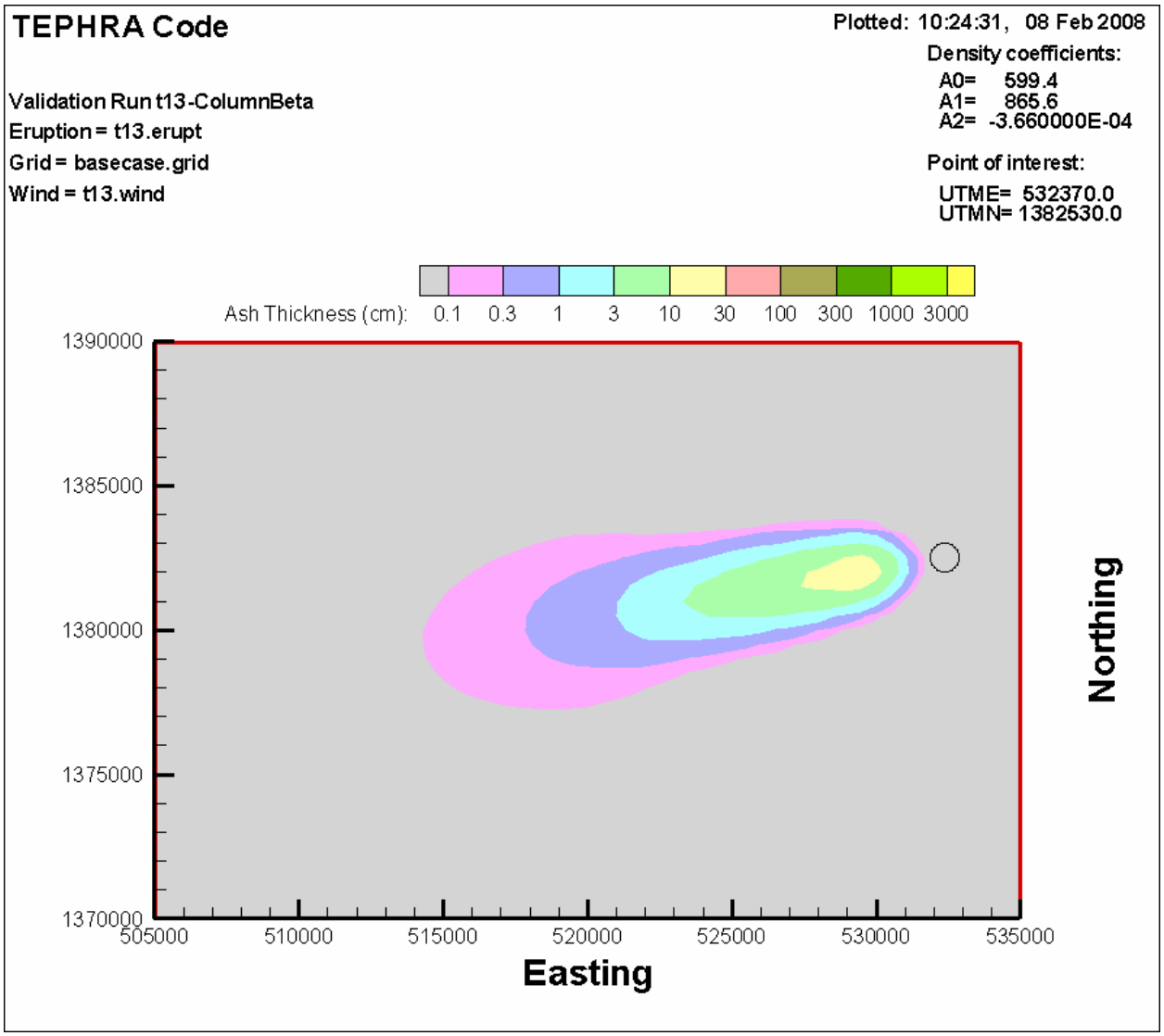


Figure 6.14-1. ***t13_1.tif*** **[Beta = 0.5]**

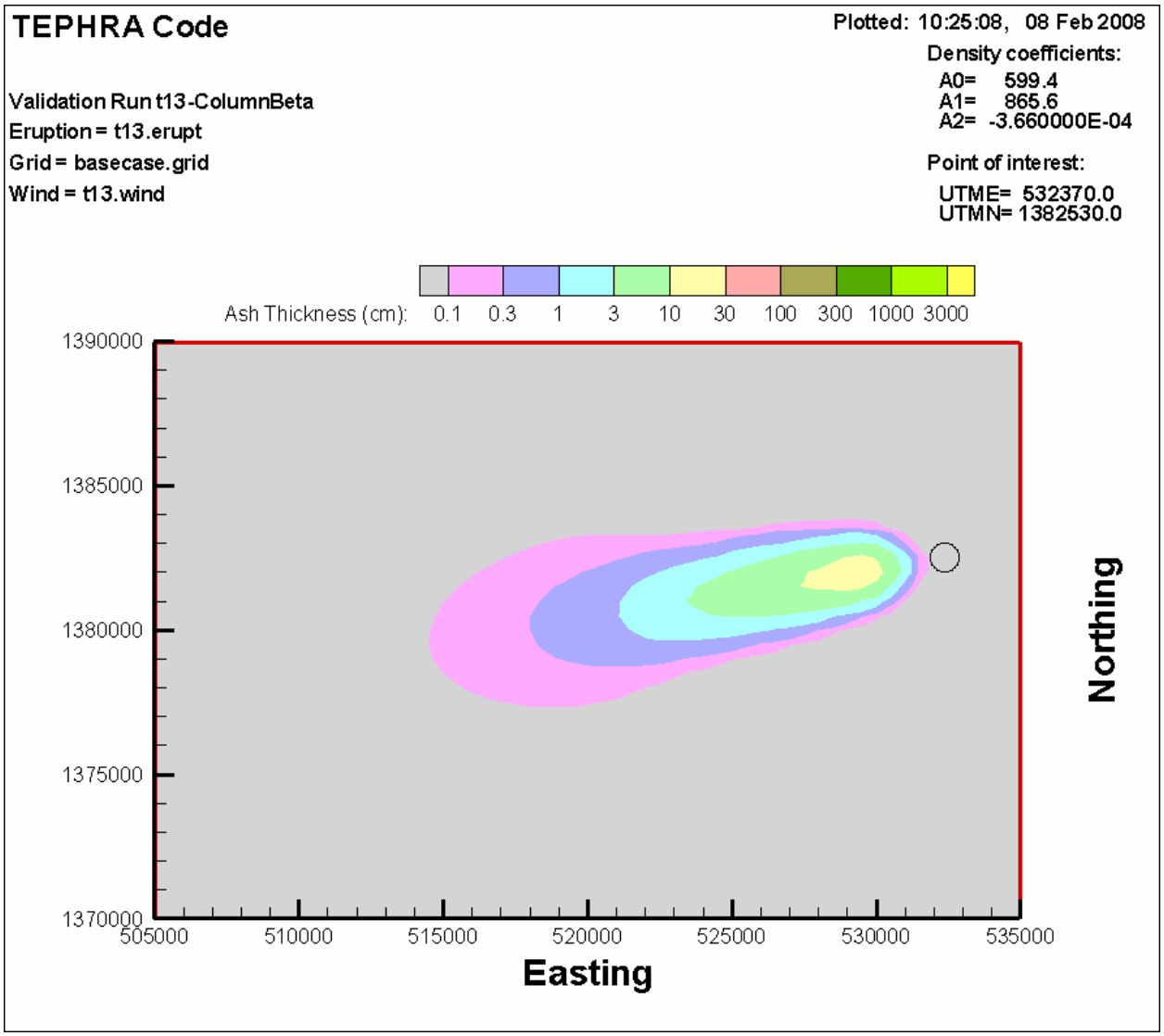


Figure 6.14-2. *t13_2.tif* [Beta = 1.0]

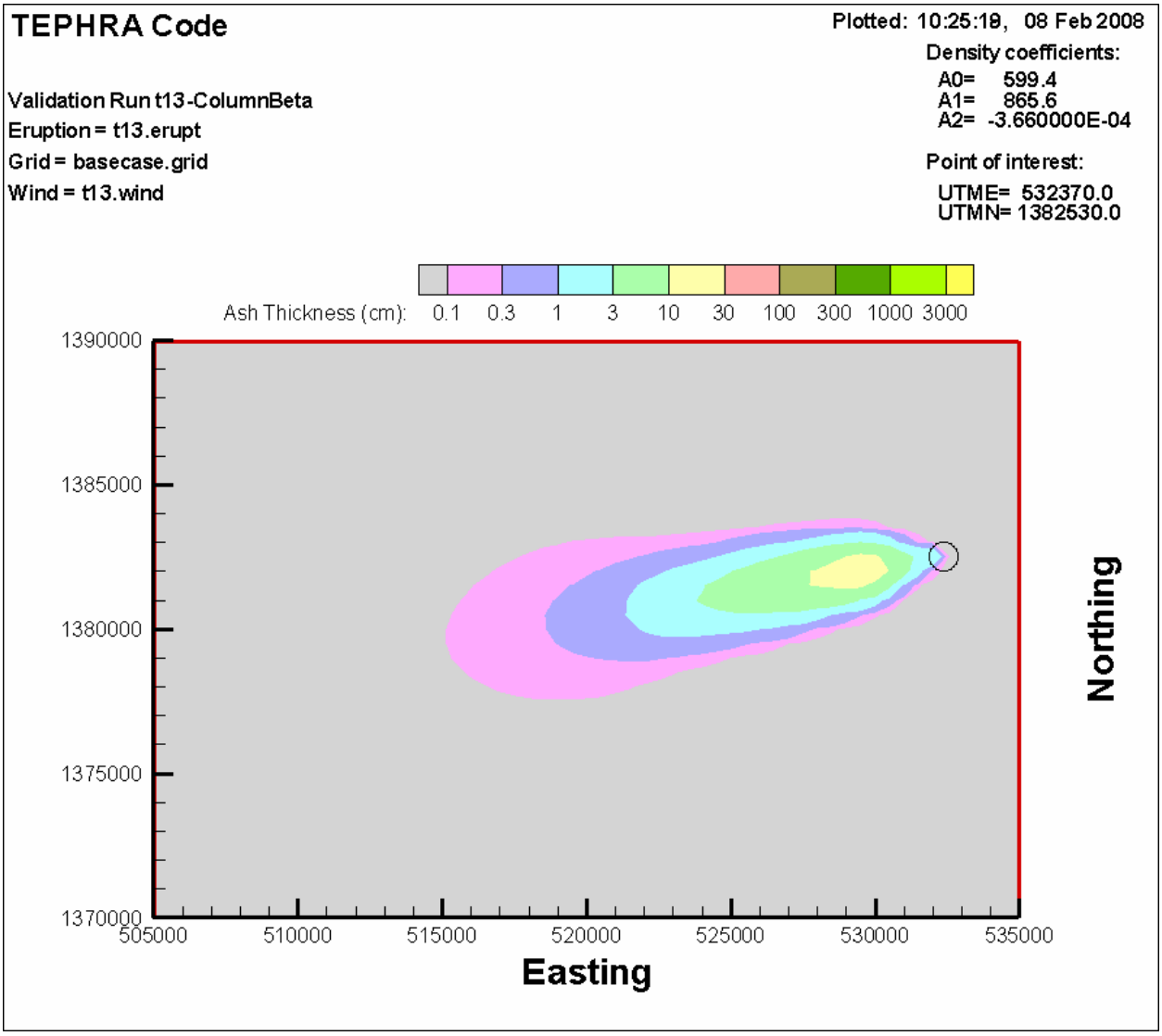


Figure 6.14-3. ***t13_3.tif*** **[Beta = 2.0]**

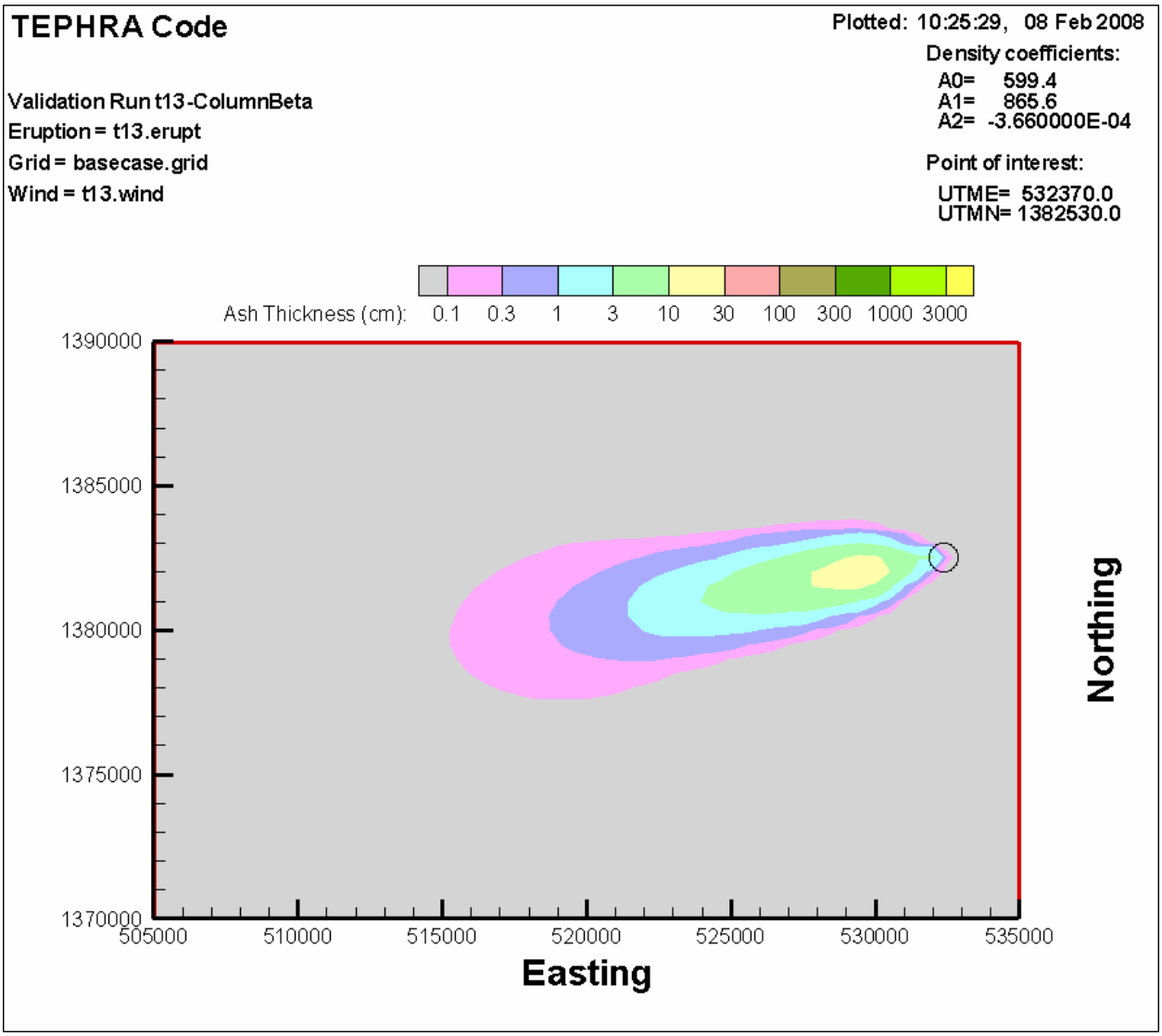


Figure 6.14-4. ***t13_4.tif*** **[Beta = 2.3]**

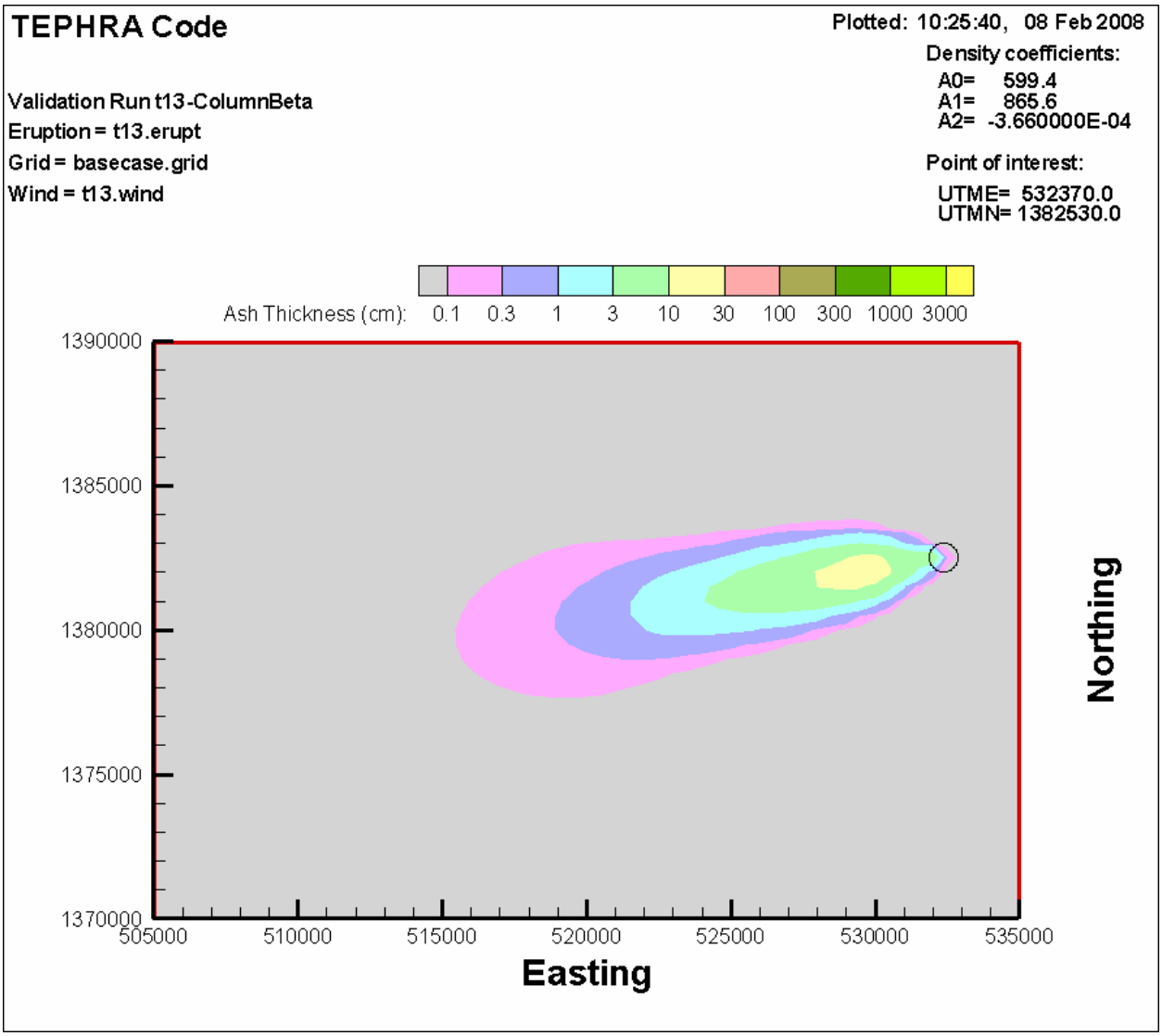


Figure 6.14-5. ***t13_5.tif*** **[Beta = 3.0]**

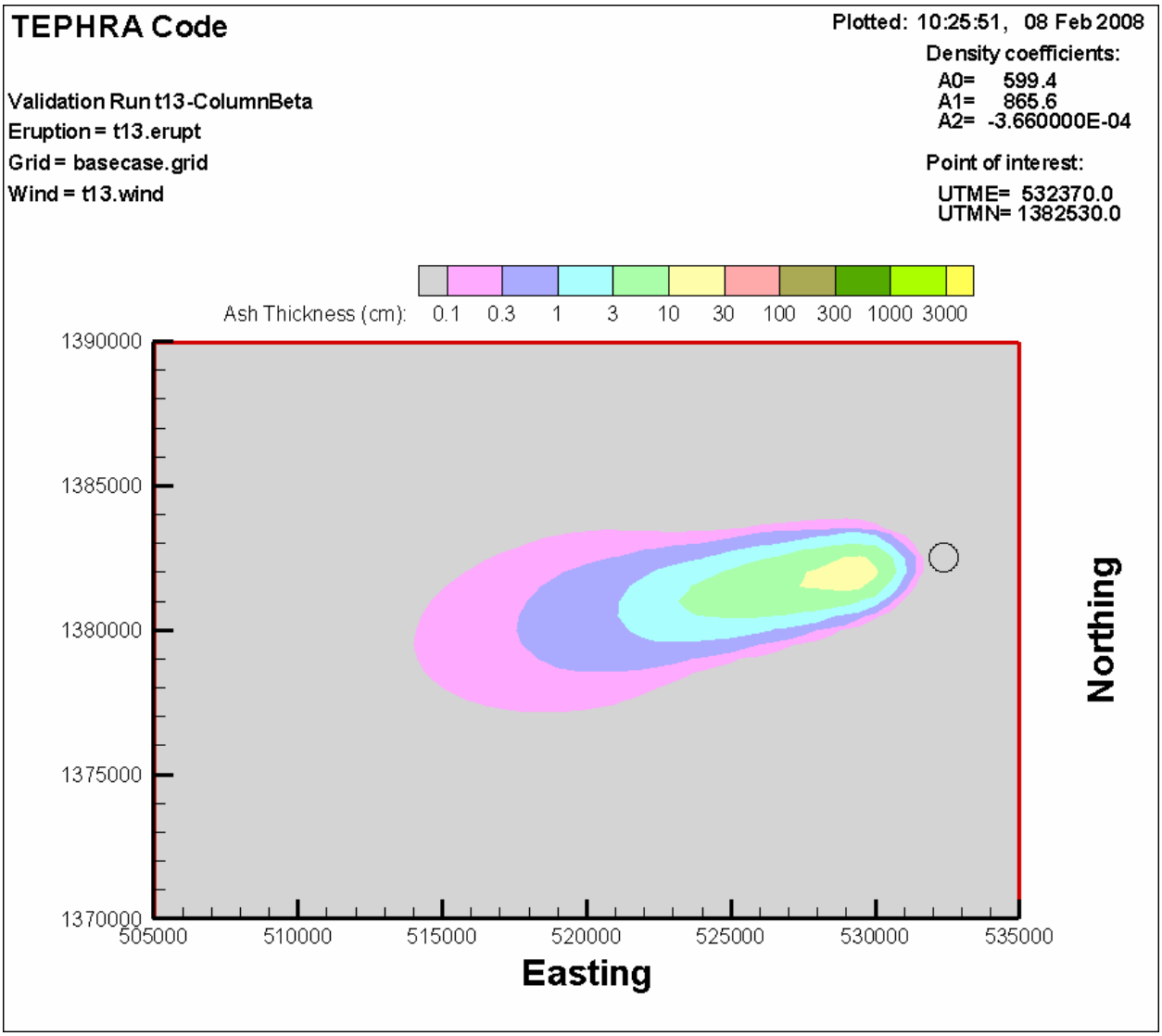


Figure 6.14-6. ***t13_6.tif*** **[Beta = 4.0]**

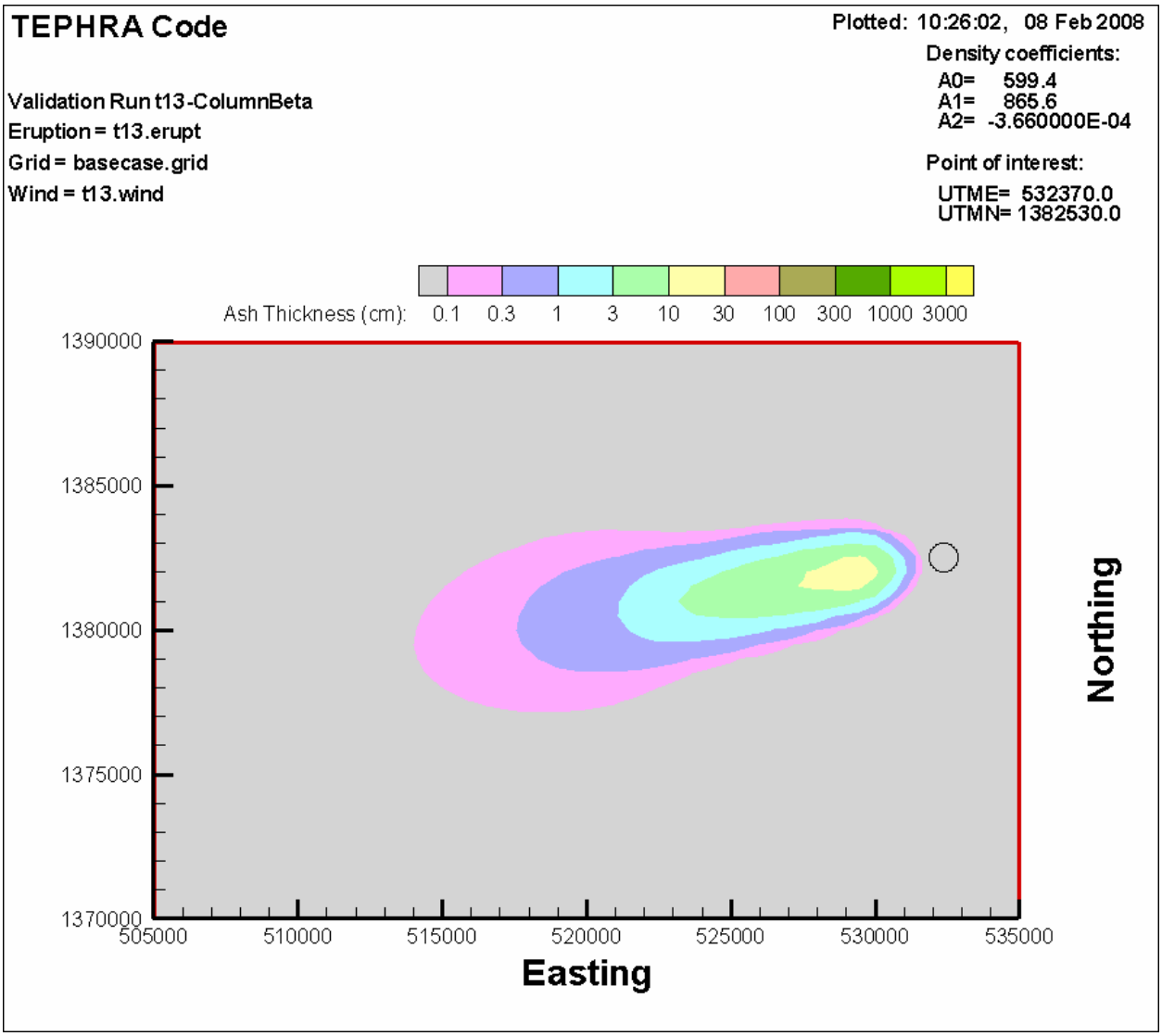


Figure 6.14-7. *t13_7.tif* [Beta = 6.0]

6.15 Test 14—Wind Layers

Objective

This test is designed to show that particles at different heights are affected appropriately by the wind profile supplied in the wind file. When particles are released from the plume, they are assigned a wind velocity vector (both speed and direction). These attributes are constant for the particles until they arrive at the deposition plane, even though they may pass through other layers with other attributes during the settling process. By changing the direction of the wind vector at different heights and limiting the column height for the first case, a significantly different deposition pattern should exist between the two cases.

Test Inputs

Table 6.15-1. TEPHRA Input File *t14_0.conf* (Plume Model = 0)

```
SEED                      6
DIFFUSION_COEFFICIENT  400.0
FALL_TIME_THRESHOLD   1080.0
LITHIC_DENSITY        2350.0
PUMICE_DENSITY        1100.0
COL_STEPS               50
PLUME_MODEL              0
PLUME_RATIO              0.001
PROB_MAP                 0
SURVIVOR                 0
ASH_ACCUM_THRESHOLD      0.0
PROB_THRESHOLD           0.0
MAX_ACCUMULATION         0
COMPLIMENT               0
WIND_INTERVAL          500.0
WIND_LEVELS              5
WIND_DAYS                1
WIND_COLUMNS             3
```

Table 6.15-2. TEPHRA Input File *t14_1.conf* (Plume Model = 1)

```
SEED                      6
DIFFUSION_COEFFICIENT  400.0
FALL_TIME_THRESHOLD   1080.0
LITHIC_DENSITY        2350.0
PUMICE_DENSITY        1100.0
COL_STEPS               50
PLUME_MODEL              1
PLUME_RATIO              0.001
PROB_MAP                 0
SURVIVOR                 0
ASH_ACCUM_THRESHOLD      0.0
PROB_THRESHOLD           0.0
MAX_ACCUMULATION         0
COMPLIMENT               0
WIND_INTERVAL          500.0
WIND_LEVELS              5
WIND_DAYS                1
WIND_COLUMNS             3
```

Table 6.15-3. TEPHRA Input File *t14_0.erupt*

```
1382530 532370 1000000000 -5.00  5.00 0.50 1 0.5 0.0 1000.00000  10. 1000  -2 -4 -3 0.1 100
```

Table 6.15-4. TEPHRA Input File *t14_1.erupt*

```
1382530 532370 1000000000 -5.00  5.00 0.50 1 0.5 0.0 2000.00000  10. 1000  -2 -4 -3 0.1 100
```

Table 6.15-5. TEPHRA Input File *t14.wind*

```
   0.0  10.0 -180.0
 500.0  10.0 -180.0
1000.0  10.0 -180.0
1500.0  10.0 -100.0
2000.0  10.0 -100.0
```

Table 6.15-6. *t2t.e* Postprocessor Input File *t14_0.t2t*

```
! Input file for program t2t.f90
!
TECPLOT_TITLE
  'TEPHRA Code Validation Run t14_0-WindLayers'
!
LABEL_1
  ' Validation Run t14_0-WindLayers'
!
LABEL_2
  ' Eruption = t14_0.erupt'
!
LABEL_3
  ' Grid = basecase.grid'
!
LABEL_4
  ' Wind = t14.wind'
!
TEPHRA_OUTPUT_FILE
  't14_0.all'
!
HEIGHT_PER_GRID_POINT_FILE
  'basecase.height'
!
MODE(individual;cumulative)
  'individual'
!
COORDINATE_SYSTEM(rectangular;cylindrical)
  'rectangular'
!
EOLIAN_AREA_LOWER_LEFT(x,y)
  505000, 1370000
!
EOLIAN_AREA_UPPER_RIGHT(x,y)
  535000, 1390000
!
ERUPTION_RANGE(start,stop)
  1,1
!
ERUPTIONS_IN_FILE
  1
```

Table 6.15-6. *t2t.e* Postprocessor Input File *t14_0.t2t* (continued)

```
!
DENSITY_COEFFICIENTS
 599.4,  865.6,  -3.66e-4
!
POINT_OF_INTEREST(UTM)
 532370.0, 1382530.0
!
! END
```

Table 6.15-7. *t2t.e* Postprocessor Input File *t14_1.t2t*

```
! Input file for program t2t.f90
!
TECPLOT_TITLE
  'TEPHRA Code Validation Run t14_1-WindLayers'
!
LABEL_1
  ' Validation Run t14_1-WindLayers'
!
LABEL_2
  ' Eruption = t14_1.erupt'
!
LABEL_3
  ' Grid = basecase.grid'
!
LABEL_4
  ' Wind = t14.wind'
!
TEPHRA_OUTPUT_FILE
  't14_1.all'
!
HEIGHT_PER_GRID_POINT_FILE
  'basecase.height'
!
MODE(individual;cumulative)
  'individual'
!
COORDINATE_SYSTEM(rectangular;cylindrical)
  'rectangular'
!
EOLIAN_AREA_LOWER_LEFT(x,y)
  505000, 1370000
!
EOLIAN_AREA_UPPER_RIGHT(x,y)
  535000, 1390000
!
ERUPTION_RANGE(start,stop)
  1,1
!
ERUPTIONS_IN_FILE
  1
!
DENSITY_COEFFICIENTS
 599.4,  865.6,  -3.66e-4
!
POINT_OF_INTEREST(UTM)
 532370.0, 1382530.0
!
! END
```

Test Procedure

The script file for this test was run in subdirectory *t14-WindLayers* and is listed in Table 6.15-8.

Table 6.15-8. Test 14 Script File *t14.run*

```
date > t14.time
mpirun -np 4 \
      ../../tephra \
      t14_0.conf     \
      t14_0.erupt  \
      basecase.grid   \
      t14.wind        \
      t14_0.all > t14_0.cum
mpirun -np 4 \
      ../../tephra \
      t14_1.conf     \
      t14_1.erupt  \
      basecase.grid   \
      t14.wind        \
      t14_1.all > t14_1.cum
date >> t14.time
../../tecplot/t2t/t2t.e <t14_0.t2t
mv t2t_ind*.tec t14_0.tec
../../tecplot/t2t/t2t.e <t14_1.t2t
mv t2t_ind*.tec t14_1.tec
```

Test Results

The isopach contour pattern in Figure 6.15-1 is consistent with a plume ratio of 0.001 and a limited column height of 1,000 m [0.62 mi] with a uniform wind field. The isopach pattern in Figure 6.15-2 shows a bifurcating ash distribution pattern that is consistent with a larger column height of 2,000 m [1.24 mi], a beta value of 10, and the wind velocity vector pointing in the −100° direction at low elevations and the −180° direction at higher elevations. This is consistent with the lower column particles receiving wind velocity attributes from the 0- to1,000-m [0- to 0.62-mi] layer and the upper column particles receiving wind velocity attributes of the 1,000- to 2,000-m [0.62- to 1.24-mi] layer.

Test Rating

Pass

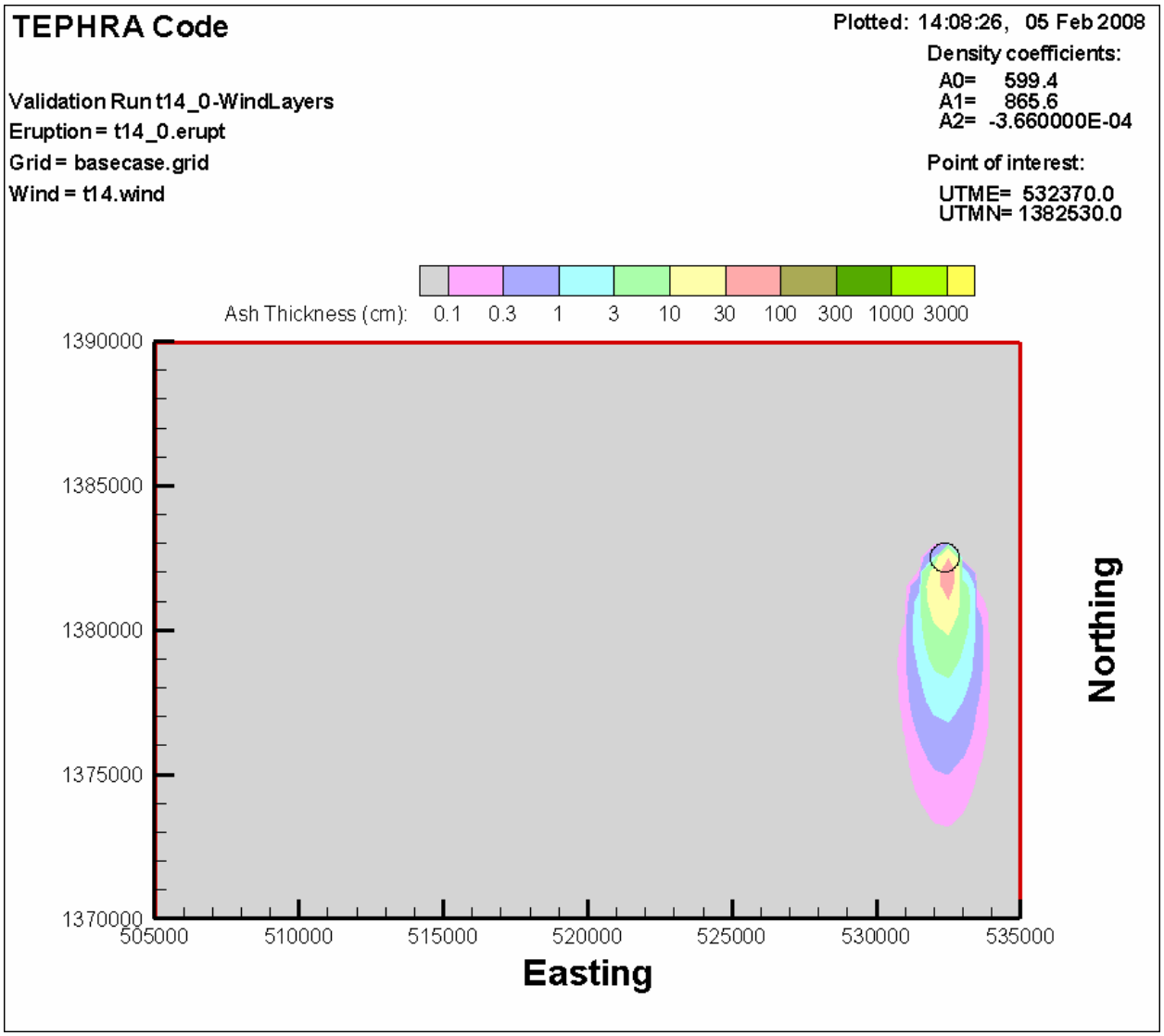


Figure 6.15-1. ***t14_0.tif*** **{Plume Model = 0; Column Height = 1,000 m [0.62 mi]}**

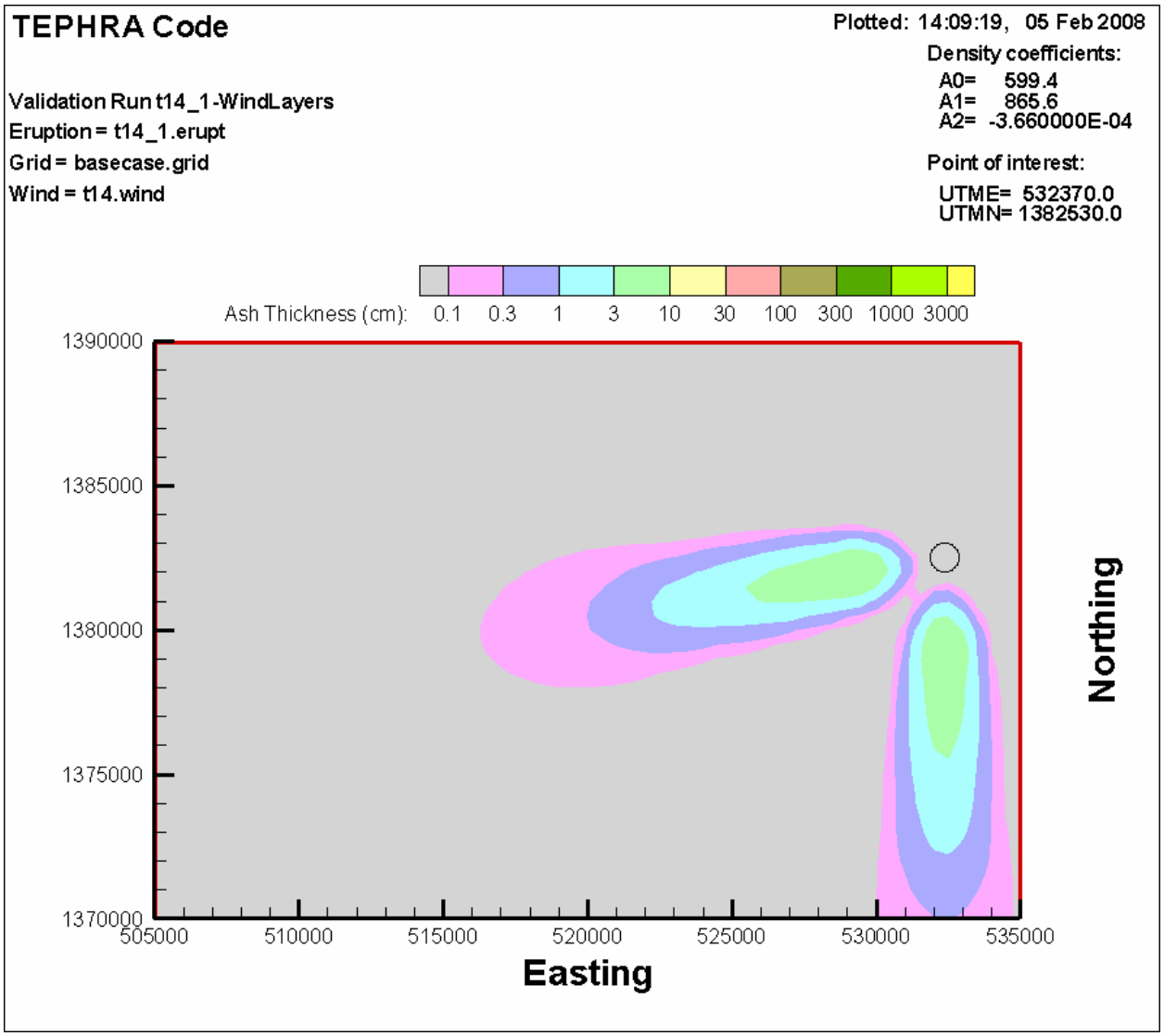


Figure 6.15-2. ***t14_1.tif*** **{Plume Model = 1; Column Height = 2,000 m [1.24 mi]}**

6.16 Test 15—Wind Speed

Objective

This test is designed to show the effect of wind speed on the ash deposition pattern. The wind direction remains unchanged, while velocity is varied from 0 to 18 m s^{-1} [59 ft s^{-1}].

Test Inputs

Table 6.16-1. TEPHRA Input File *t15.conf*

```
SEED                     6
DIFFUSION_COEFFICIENT  400.0
FALL_TIME_THRESHOLD   1080.0
LITHIC_DENSITY        2350.0
PUMICE_DENSITY        1100.0
COL_STEPS               50
PLUME_MODEL              0
PLUME_RATIO              0.001
PROB_MAP                 0
SURVIVOR                 0
ASH_ACCUM_THRESHOLD      0.0
PROB_THRESHOLD           0.0
MAX_ACCUMULATION         0
COMPLIMENT               0
WIND_INTERVAL          500.0
WIND_LEVELS              5
WIND_DAYS               10
WIND_COLUMNS             3
```

Table 6.16-2. TEPHRA Input File *t15.erupt*

```
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 1000  -2 -4 -3 0.5 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 1000  -2 -4 -3 0.5 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 1000  -2 -4 -3 0.5 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 1000  -2 -4 -3 0.5 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 1000  -2 -4 -3 0.5 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 1000  -2 -4 -3 0.5 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 1000  -2 -4 -3 0.5 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 1000  -2 -4 -3 0.5 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 1000  -2 -4 -3 0.5 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 1000  -2 -4 -3 0.5 100
```

Table 6.16-3. TEPHRA Input File *t15.wind*

```
   0.0   0.0 -100.0
 500.0   0.0 -100.0
1000.0   0.0 -100.0
1500.0   0.0 -100.0
2000.0   0.0 -100.0
   0.0   2.0 -100.0
 500.0   2.0 -100.0
1000.0   2.0 -100.0
1500.0   2.0 -100.0
2000.0   2.0 -100.0
   0.0   4.0 -100.0
500.0   4.0 -100.0
1000.0   4.0 -100.0
1500.0   4.0 -100.0
2000.0   4.0 -100.0
  0.0   6.0 -100.0
```

Table 6.16-3. TEPHRA Input File *t15.wind* (continued)

```
500.0   6.0 -100.0
1000.0   6.0 -100.0
1500.0   6.0 -100.0
2000.0   6.0 -100.0
   0.0   8.0 -100.0
 500.0   8.0 -100.0
1000.0   8.0 -100.0
1500.0   8.0 -100.0
2000.0   8.0 -100.0
   0.0  10.0 -100.0
 500.0  10.0 -100.0
1000.0  10.0 -100.0
1500.0  10.0 -100.0
2000.0  10.0 -100.0
   0.0  12.0 -100.0
 500.0  12.0 -100.0
1000.0  12.0 -100.0
1500.0  12.0 -100.0
2000.0  12.0 -100.0
   0.0  14.0 -100.0
 500.0  14.0 -100.0
1000.0  14.0 -100.0
1500.0  14.0 -100.0
2000.0  14.0 -100.0
   0.0  16.0 -100.0
 500.0  16.0 -100.0
1000.0  16.0 -100.0
1500.0  16.0 -100.0
2000.0  16.0 -100.0
   0.0  18.0 -100.0
 500.0  18.0 -100.0
1000.0  18.0 -100.0
1500.0  18.0 -100.0
2000.0  18.0 -100.0
```

Table 6.16-4. *t2t.e* Postprocessor Input File *t15ind.t2t*

```
! Input file for program t2t.f90
!
TECPLOT_TITLE
  'TEPHRA Code Validation Run t15-WindSpeed'
!
LABEL_1
  ' Validation Run t15-WindSpeed'
!
LABEL_2
  ' Eruption = t15.erupt'
!
LABEL_3
  ' Grid = basecase.grid'
!
LABEL_4
  ' Wind = t15.wind'
!
TEPHRA_OUTPUT_FILE
  't15.all'
```

Table 6.16-4. *t2t.e* Postprocessor Input File *t15ind.t2t* (continued)

```
!
HEIGHT_PER_GRID_POINT_FILE
  'basecase.height'
!
MODE(individual;cumulative)
  'individual'
!
COORDINATE_SYSTEM(rectangular;cylindrical)
  'rectangular'
!
EOLIAN_AREA_LOWER_LEFT(x,y)
  505000, 1370000
!
EOLIAN_AREA_UPPER_RIGHT(x,y)
  535000, 1390000
!
ERUPTION_RANGE(start,stop)
  1,10
!
ERUPTIONS_IN_FILE
  10
!
DENSITY_COEFFICIENTS
 599.4,  865.6,  -3.66e-4
!
POINT_OF_INTEREST(UTM)
 532370.0, 1382530.0
!
! END
```

Test Procedure

The script file for this test was run in subdirectory *t15-WindSpeed* and is listed in Table 6.16-5.

Table 6.16-5. Test 15 Script File *t15.run*

```
date > t15.time
mpirun -np 4 \
      ../../tephra \
      t15.conf     \
      t15.erupt  \
      basecase.grid   \
      t15.wind        \
      t15.all > t15.cum
date >> t15.time
../../tecplot/t2t/t2t.e <t15ind.t2t
mv t2t_ind*.tec t15ind.tec
../../tecplot/t2t/t2t.e <t15cum.t2t
mv t2t_cum*.tec t15cum.tec
```

Test Results

The isopach contour pattern in Figure 6.16-1 is circular, which is consistent with a wind velocity of 0 m s^{-1}. The isopach contour in Figure 6.16-2 is elongated in the wind direction and is consistent with the particle deposition model implemented in the TEPHRA code.

Test Rating

Pass

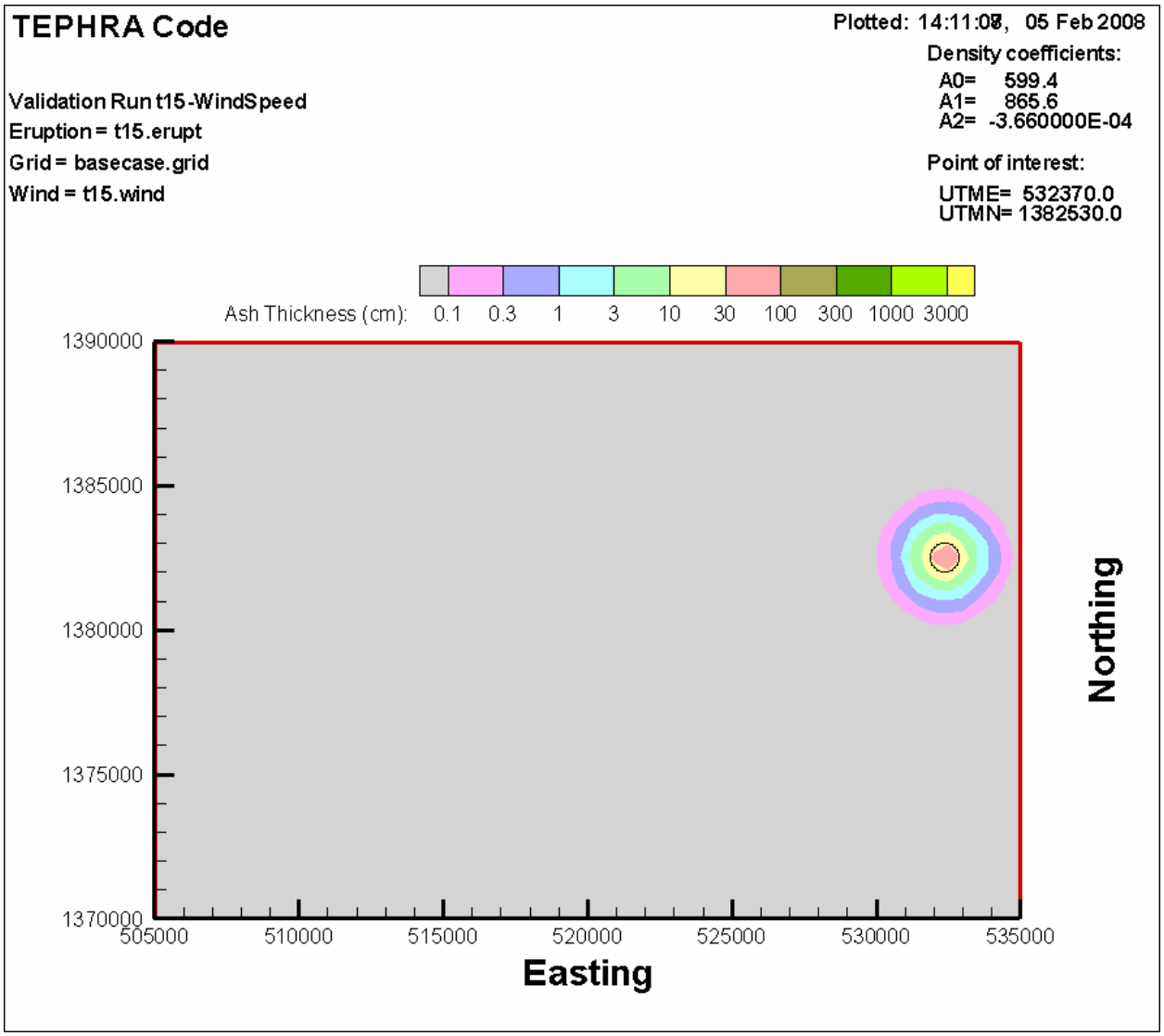


Figure 6.16-1. ***t15_0.tif*** **{Wind Speed = 0 m s^{-1} [0 ft s^{-1}]}**

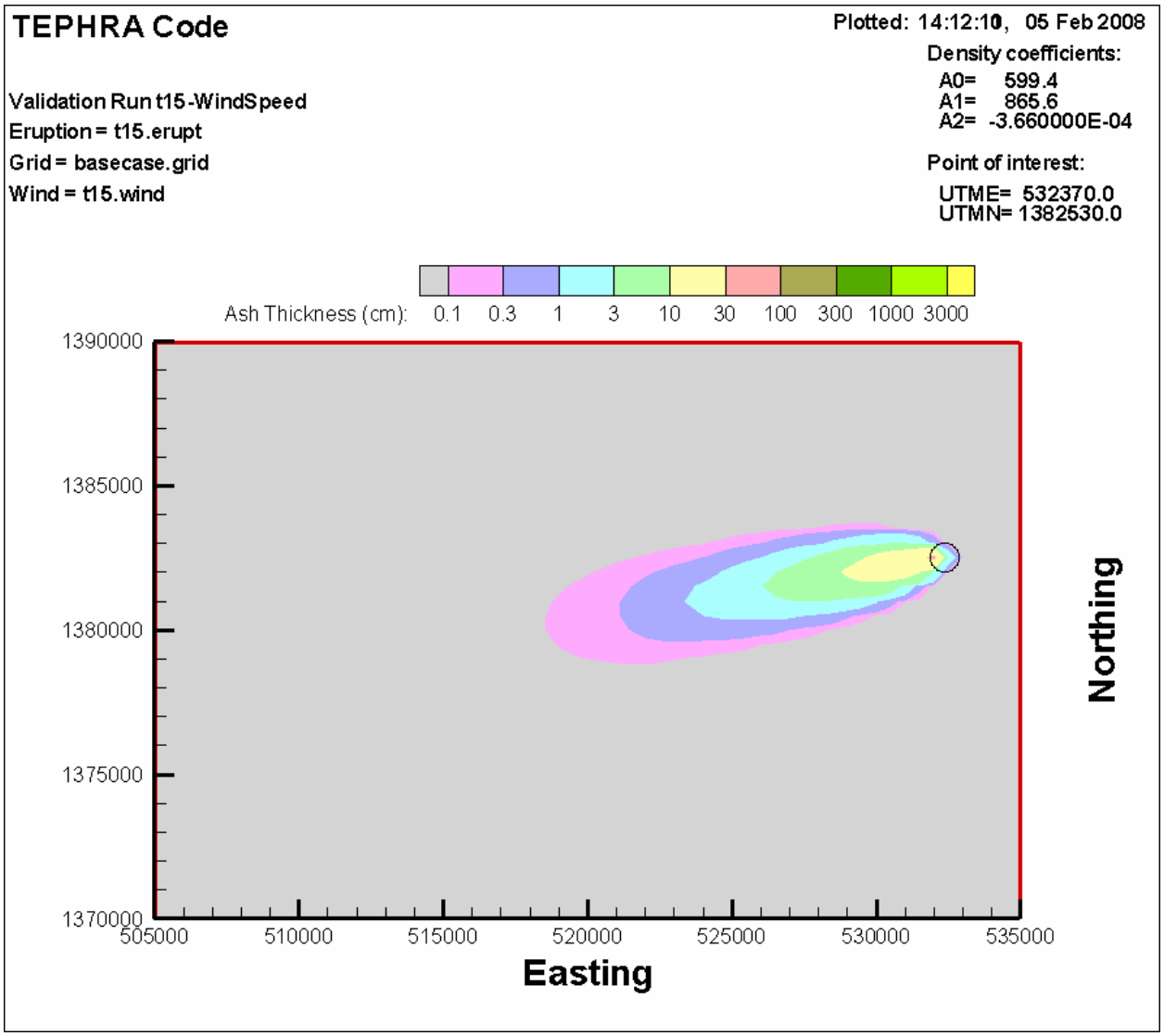


Figure 6.16-2. ***t15_10mps.tif*** **{Wind Speed = 10 m s^{-1} [33 ft s^{-1}]}**

6.17 Test 16—Wind File

Objective

This test is designed to show that particles at different heights are affected appropriately by wind profiles of varied structure in the wind file. By changing the direction of the wind vector at different heights and direction for different levels, the deposition patterns can be compared for consistency. Four separate eruptions are analyzed using one wind file. Each eruption receives wind parameters for three levels of a different wind day.

Test Inputs

Table 6.17-1. TEPHRA Input File *t16.conf*

```
SEED                     6
DIFFUSION_COEFFICIENT  400.0
FALL_TIME_THRESHOLD   1080.0
LITHIC_DENSITY        2350.0
PUMICE_DENSITY        1100.0
COL_STEPS               50
PLUME_MODEL              0
PLUME_RATIO              0.001
PROB_MAP                 0
SURVIVOR                 0
ASH_ACCUM_THRESHOLD      0.0
PROB_THRESHOLD           0.0
MAX_ACCUMULATION         0
COMPLIMENT               0
WIND_INTERVAL           1000.0
WIND_LEVELS                3
WIND_DAYS                5
WIND_COLUMNS             3
```

Table 6.17-2. TEPHRA Input File *t16.erupt*

```
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 1000  -2 -4 -3 0.5 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 1000  -2 -4 -3 0.5 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 1000  -2 -4 -3 0.5 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 1000  -2 -4 -3 0.5 100
1382530 532370 1000000000 -5.00  5.00  0.50 1 0.5    0.0 2000.00000  0.5 1000  -2 -4 -3 0.5 100
```

Table 6.17-3. TEPHRA Input File *t16.wind*

```
   0.0  10.0  -90.0
1000.0  10.0  -90.0
2000.0  10.0  -90.0
   0.0  10.0 -180.0
1000.0  10.0 -180.0
2000.0  10.0 -180.0
   0.0  10.0 -180.0
1000.0  10.0 -180.0
2000.0  10.0  -90.0
   0.0  10.0  -90.0
1000.0  10.0 -180.0
2000.0  10.0 -180.0
   0.0  10.0  -90.0
1000.0  10.0 -180.0
2000.0   0.0 -180.0
```

Table 6.17-4. *t2t.e* Postprocessor Input File *t16ind.t2t*

```
! Input file for program t2t.f90
!
TECPLOT_TITLE
  'TEPHRA Code Validation Run t16-WindFile'
!
LABEL_1
  ' Validation Run t16-WindFile'
!
LABEL_2
  ' Eruption = t16.erupt'
!
LABEL_3
  ' Grid = basecase.grid'
!
LABEL_4
  ' Wind = t16.wind'
!
TEPHRA_OUTPUT_FILE
  't16.all'
!
HEIGHT_PER_GRID_POINT_FILE
  'basecase.height'
!
MODE(individual;cumulative)
  'individual'
!
COORDINATE_SYSTEM(rectangular;cylindrical)
  'rectangular'
!
EOLIAN_AREA_LOWER_LEFT(x,y)
  505000, 1370000
!
EOLIAN_AREA_UPPER_RIGHT(x,y)
  535000, 1390000
!
ERUPTION_RANGE(start,stop)
  1,5
!
ERUPTIONS_IN_FILE
   5
!
DENSITY_COEFFICIENTS
 599.4,  865.6,  -3.66e-4
!
POINT_OF_INTEREST(UTM)
 532370.0, 1382530.0
!
! END
```

Test Procedure

The script file for this test was run in subdirectory *t16-WindFile* and is listed in Table 6.17-5.

Table 6.17-5. Test 16 Script File *t16.run*

```
date > t16.time
mpirun -np 4 \
      ../../tephra \
      t16.conf     \
      t16.erupt  \
      basecase.grid   \
      t16.wind        \
      t16.all > t16.cum
date >> t16.time
../../tecplot/t2t/t2t.e <t16ind.t2t
mv t2t_ind*.tec t16ind.tec
../../tecplot/t2t/t2t.e <t16cum.t2t
mv t2t_cum*.tec t16cum.tec
```

Test Results

The isopach contour pattern in Figure 6.17-1 is consistent with a wind direction of −90° at all levels. The isopach contour pattern in Figure 6.17-2 is consistent with a wind direction of −180° at all levels. The isopach contour pattern in Figure 6.17-3 shows the effect of two wind directions when the two uppermost wind entries have different wind direction values. However, the lower level winds in the −180° direction have no effect on the particles released in the −90° direction. This is the expected result.

The isopach contour pattern in Figure 6.17-4 is consistent with a wind direction of −180° at all levels except the first, because the first level is at 0 m [0 ft s^{-1}] elevation and is not used. The contour pattern in Figure 6.17-5 shows that the upper layer particles, which are assigned a 0 velocity wind vector, retain the 0 velocity value for all subsequent layers during settling. This is the expected result for the integration algorithm used in the TEPHRA code.

Test Rating

Pass

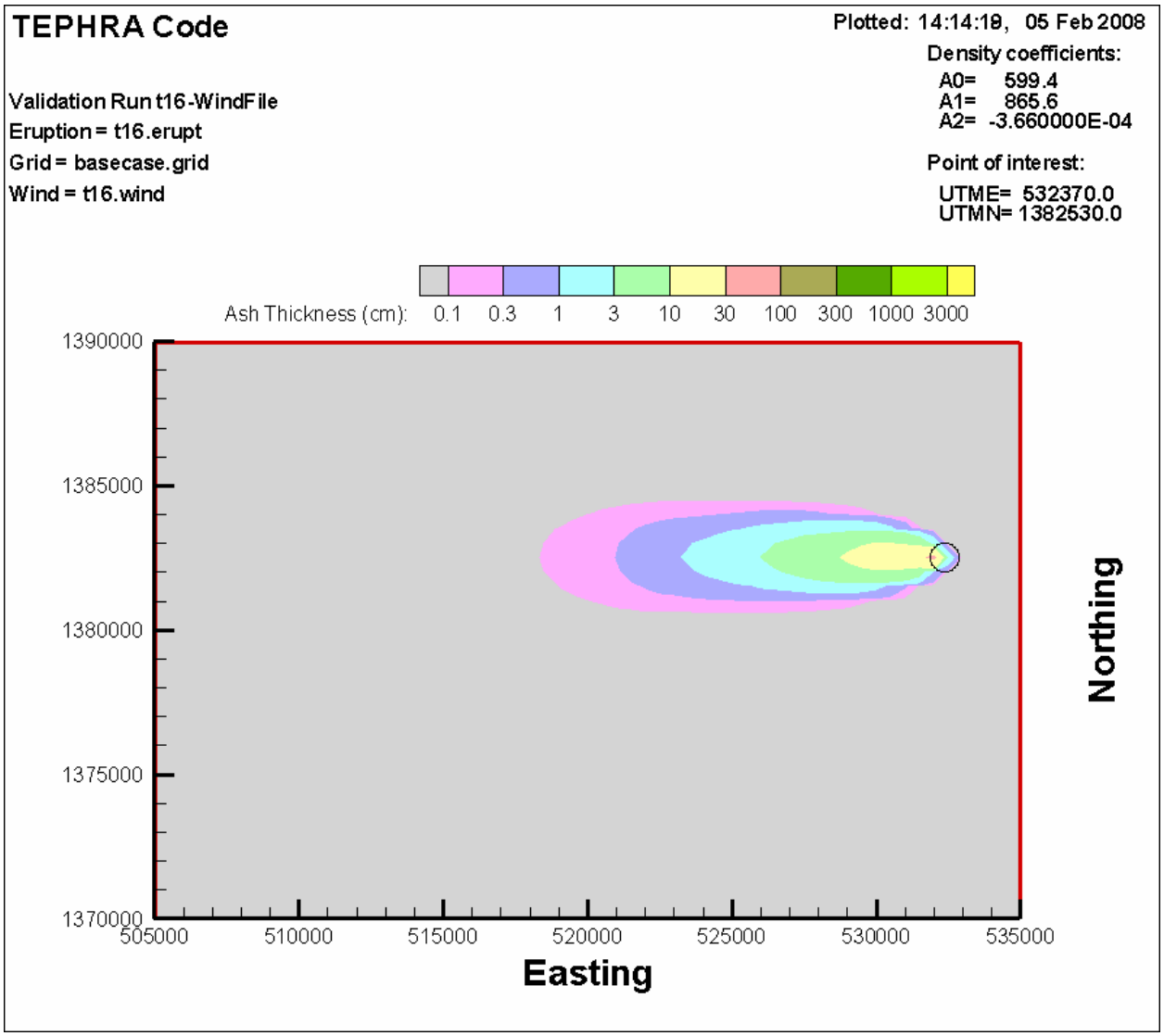


Figure 6.17-1. *t16_1.tif* {Wind Velocity = 10 m s^{-1} [33 ft s^{-1}] at All Levels; Wind Direction = −90°}

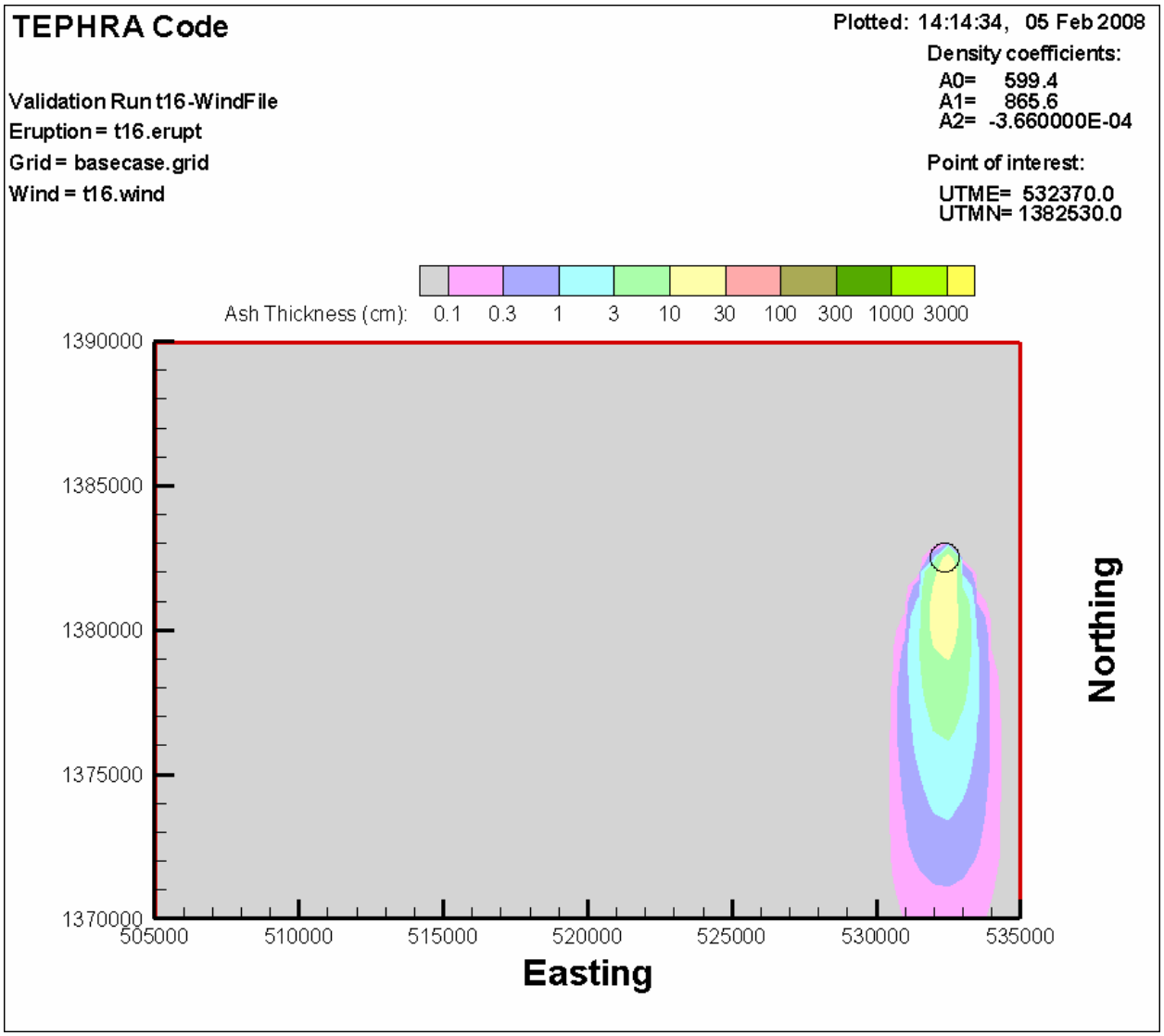


Figure 6.17-2. *t16_2.tif* {Plume Wind Velocity = 10 m s^{-1} [33 ft s^{-1}] at All Levels; Wind Direction = −180°}

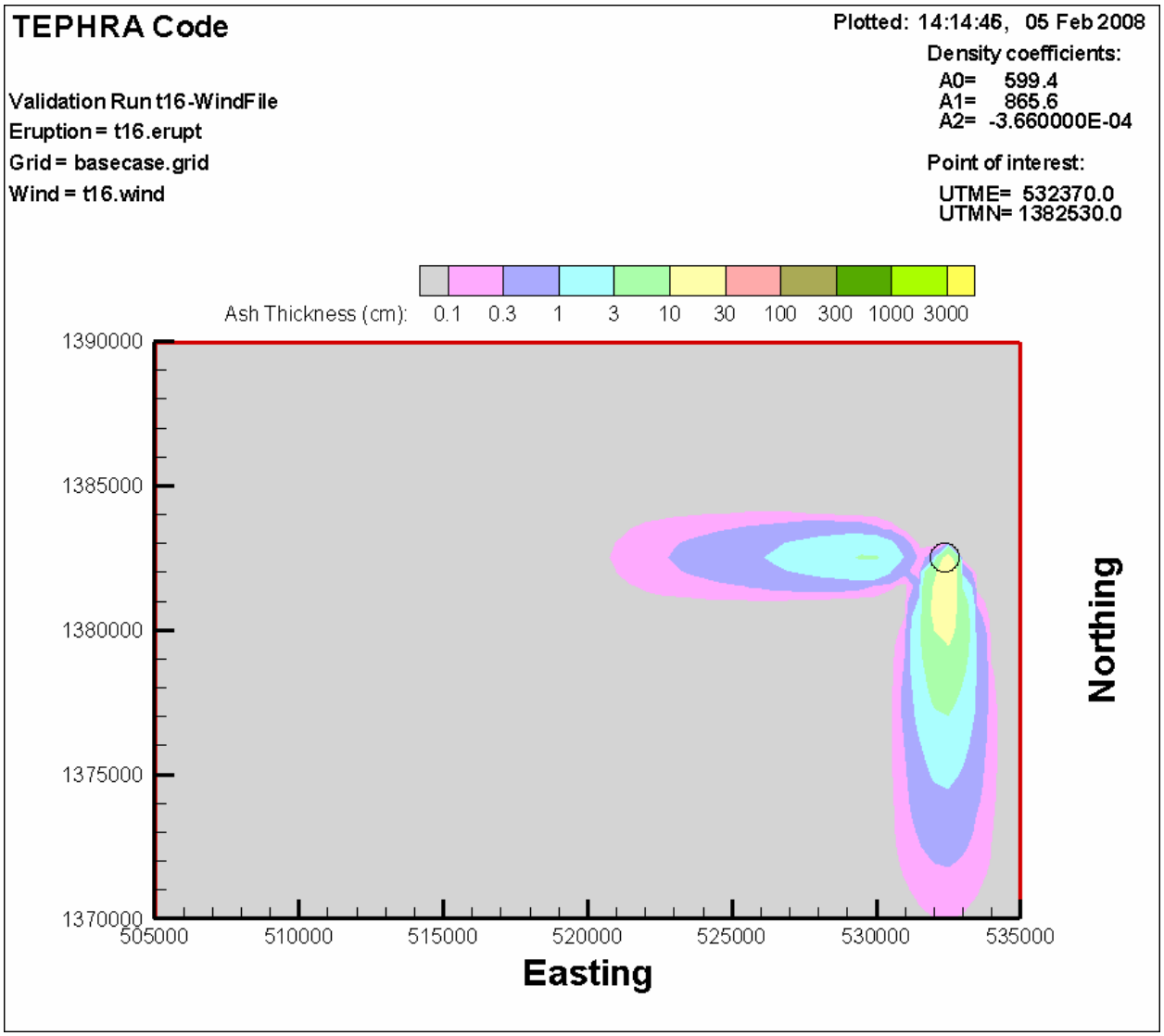


Figure 6.17-3. ***t16_3.tif*** **{Plume Wind Velocity = 10 m s^{-1} [33 ft s^{-1}] at All Levels; Wind Direction = −180° Lower Two Levels and −90° at Uppermost Level}**

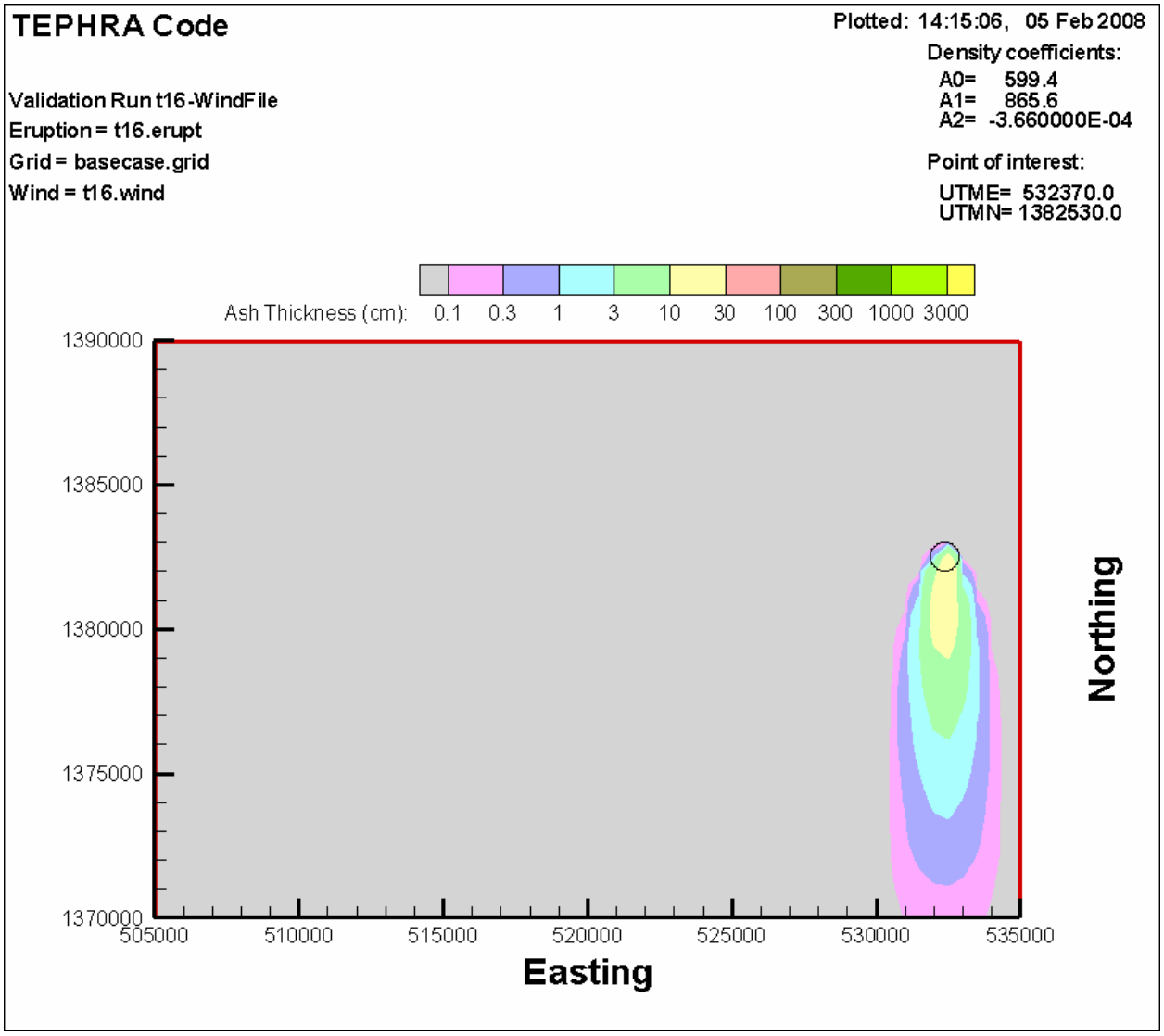


Figure 6.17-4. ***t16_4.tif*** **{Plume Wind Velocity = 10 m s^{-1} [33 ft s^{-1}] at All Levels; Wind Direction = −90° at Lowest Level and −180° at Upper Two Levels}**

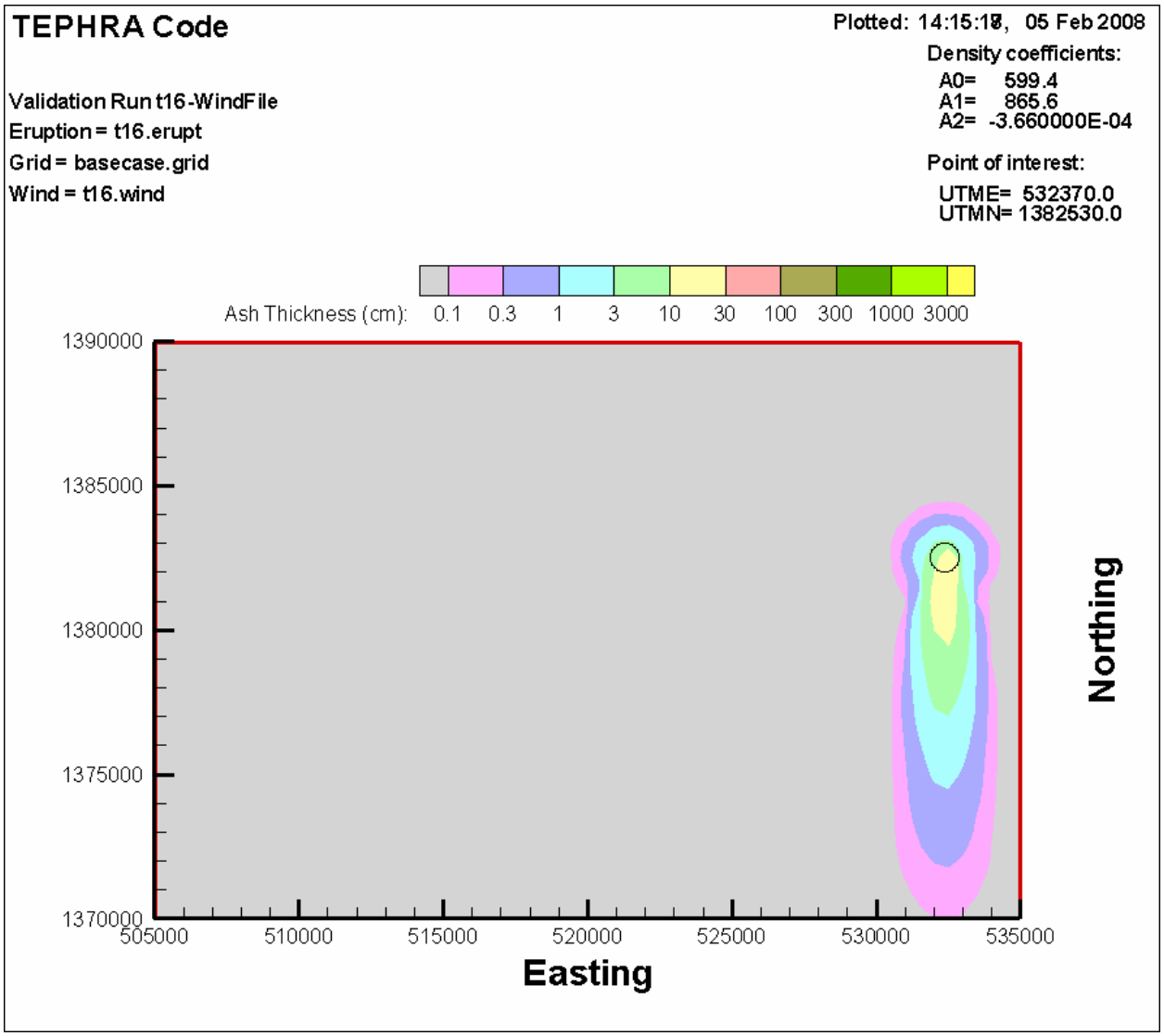


Figure 6.17-5. ***t16_5.tif*** **{Plume Wind Velocity = 10 m s^{-1} [33 ft s^{-1}] at Lower Two Levels; Wind Velocity = 0 m s^{-1} [0 ft s^{-1}] at Highest Level; Wind Direction = −90° at Lowest Level and −180° at Upper Two Levels}**

6.18 Test 17—Cerro Negro

Objective

In addition to the parameter-oriented software validation tests, a simulation of the 1995 Cerro Negro eruption was performed so that TEPHRA Version 1.0 results for ash thickness could be compared to measured values. The objective of this comparison is a qualitative test for reasonableness of results. Quantitative comparisons of results will be included and discussed. However, a quantitative test criterion is not applied, because the entire eruption was not modeled.

Test Inputs

Whereas intermittent explosive activity and tephra ejection resulted in tephra transport and deposition from differing eruption characteristics and atmospheric conditions (Global Volcanism Network, 1995), the TEPHRA Version 1.0 code was executed to simulate the 4-day period of late-phase activity that sustained a continuous tephra column (November 29–December 2, 1995). Many of the input parameters are consistent with those Hill, et al. (1998) used in a previous comparison for a different theoretical tephra dispersal model. Notable differences are mentioned separately.

Figure 16.18-1(a) shows the sustained tephra eruption on November 30, 1995. As indicated in Figure 16.18-1(b), 80 percent of tephra mass was released from the upper quarter of the eruption column and 20 percent of tephra mass was released from the lower three-quarters of the eruption column. The PLUME_MODEL parameter was set to zero so that the PLUME_RATIO parameter could be used to account for this tephra distribution within the column. Two PLUME_RATIO parameter values of 0.75 and 0.01 were specified with total tephra fractions of 0.73 and 0.27, respectively. A PLUME_RATIO of 0.75 corresponds to a uniform tephra mass distribution in the top quarter of the column. A PLUME_RATIO of 0.01 corresponds to a uniform tephra mass distribution for release from the top 99 percent of the column. For this case, 27 percent of the total tephra is distributed uniformly over the entire column, wherein about 7 percent applies to the upper quarter of the column and 20 percent applies to the lower three-quarters of the column. A combination of these PLUME_RATIO cases produces the desired tephra mass distribution shown in Figure 6.18-1(b).

TEPHRA Version 1.0 accepts wind field inputs that can account for variations in wind speed with height above the ground surface. To exercise this feature of the code, a wind profile was specified for the sustained Cerro Negro eruption. The shape of the wind profile was based on measurements taken above Managua, Nicaragua (Douglas, et al., 2003). Douglas, et al. (2003, Figure 6-12) presented mean wind speed profiles by month for the annual cycle. The month of December was selected to correspond to the month of the eruption being modeled, and wind speed values were approximated from the plotted profile to be representative of 6 equally spaced wind layers between the top of the 2,400 m [7,874 ft] column and ground surface. Because winds during the sustained Cerro Negro eruption were well constrained between 8 and 10 m s^{-1} [26 and 33 ft s^{-1}] (Global Volcanism Network, 1995; Hill, et al., 1998), the average wind speed over the entire column height was computed. The (unadjusted) average wind speed from the measured wind profile was 10 m s^{-1} [33 ft s^{-1}]. Because this long-term value is slightly higher than the ~9 m s^{-1} [30 ft s^{-1}] winds observed during the eruption, the wind speeds for each layer were adjusted so that the average over the entire column height would be consistent with

a mean wind speed of 9 m s^{-1} [30 ft s^{-1}], while maintaining the same wind profile shape. Table 6.18-1 presents the unadjusted and adjusted wind profiles.

Adjusted values were scaled down to yield an average of 9 m s^{-1} [30 ft s^{-1}] over the 2,400 m [7,874 ft] column height. The adjusted wind speed values were used for the TEPHRA Version 1.0 simulation.

Table 6.18-1. Unadjusted and Adjusted Wind Speed Profiles for Managua, Nicaragua, in December

Wind layer heights above the ground surface (m)	Unadjusted wind speed (m s^{-1})	Adjusted wind speed (m s^{-1})
0 – 400	6	5
400 – 800	8	7
800 – 1200	11	10
1200 – 1600	12	11
1600 – 2000	12	11
2000 – 2400	11	10
Column average	10	9

The bulk density for Cerro Negro tephra varied with distance from the vent and decreased from about 1.2 g cm^{-3} [75 lb ft^{-3}] at 1 km [0.62 mi] from the vent to about 0.6 g cm^{-3} [37.5 lb ft^{-3}] at a distance of 20 km [12.4 mi]. The ash density values affect the calculated tephra thicknesses across the proximal, medial, and distal regions. The density coefficients used in this analysis are based on field-measured values and create a more accurate isopach map of tephra thickness and dispersal than a constant density value.

The following equation from B. Hill[1] is used to determine the ash density as a function of radial distance from the vent. The formula is based on field data collected and/or compiled by B. Hill, a member of the field team observing the Cerro Negro eruption.

$$\text{AshDensity}(r) = a0 + a1 * e^{(a2*r)} \qquad (6.18\text{-}1)$$

where

a0 = 599.4 kg m^{-3}
a1 = 865.6 kg m^{-3}
a2 = −3.66e-04 m^{-1}
r = radial distance from the vent in meters

The following relationship for bulk density is used to convert calculated values of deposited tephra mass per unit area to deposit thickness in centimeters.

$$\text{AshThickness} = \text{tephra\_mass} * 100/\text{AshDensity}(r) \qquad (6.18\text{-}2)$$

Tables 6.18-2 through 6.18-4 display the input files and parameter values for the first TEPHRA Version 1.0 simulation.

[1] Hill, B. "CN1295_Densities.xls." CNWRA Scientific Notebook #088. San Antonio, Texas: CNWRA. 1995.

Table 6.18-2. TEPHRA Input File *CN_1.conf*

```
SEED                      6
DIFFUSION_COEFFICIENT  400.0
FALL_TIME_THRESHOLD   1080.0
LITHIC_DENSITY        2350.0
PUMICE_DENSITY        1100.0
COL_STEPS              100
PLUME_MODEL              0
PLUME_RATIO              0.75
PROB_MAP                 0
SURVIVOR                 0
ASH_ACCUM_THRESHOLD      0.0
PROB_THRESHOLD           0.0
MAX_ACCUMULATION         0
COMPLIMENT               0
WIND_INTERVAL          400.0
WIND_LEVELS              7
WIND_DAYS               1
WIND_COLUMNS             3
```

Table 6.18-3. TEPHRA Input File *CN_1.erupt*

```
1382530 532370 2518500000 -5.00  5.00 0.50 1 0.5 5.0 2400.00000  0.5 3450  -2 -4 -3 0.1 100
```

Table 6.18-4. TEPHRA Input File *CN.wind*

```
   0.0   5.0 -110.0
 400.0   5.0 -110.0
 800.0   7.0 -110.0
1200.0  10.0 -110.0
1600.0  11.0 -110.0
2000.0  11.0 -110.0
2400.0  10.0 -110.0
```

Tables 6.18-4, 6.18-5, and 6.18-6 display the input files and parameter values for the second TEPHRA Version 1.0 simulation. The same wind input file (Table 6.18-4) was used for both simulations.

Table 6.18-5. TEPHRA Input File *CN_2.conf*

```
SEED                      6
DIFFUSION_COEFFICIENT  400.0
FALL_TIME_THRESHOLD   1080.0
LITHIC_DENSITY        2350.0
PUMICE_DENSITY        1100.0
COL_STEPS              100
PLUME_MODEL              0
PLUME_RATIO              0.01
PROB_MAP                 0
SURVIVOR                 0
ASH_ACCUM_THRESHOLD      0.0
PROB_THRESHOLD           0.0
MAX_ACCUMULATION         0
COMPLIMENT               0
WIND_INTERVAL            400.0
WIND_LEVELS              7
WIND_DAYS                1
WIND_COLUMNS             3
```

Table 6.18-6. TEPHRA Input File *CN_2.erupt*
1382530 532370 2518500000 -5.00 5.00 0.50 1 0.5 5.0 2400.00000 0.5 3450 -2 -4 -3 0.1 100

Test Procedure

The script file for this test was run in subdirectory *CerroNegro* and is listed in Table 6.18-7.

Table 6.18-7. Test 16 Script File *CN.run*

```
date > CN.time
mpirun -np 4 \
      ../../tephra \
      CN_1.conf \
      CN_1.erupt \
      basecase.grid \
      CN.wind \
      CN_1.all > CN_1.cum
mpirun -np 4 \
      ../../tephra \
      CN_2.conf \
      CN_2.erupt \
      basecase.grid \
      CN.wind \
      CN_2.all > CN_2.cum
date >> CN.time
../../tecplot/t2t/t2t.e <CN_1.t2t
mv t2t_ind*.tec CN_1_ind.tec
../../tecplot/t2t/t2t.e <CN_2.t2t
mv t2t_ind*.tec CN_2_ind.tec
cat CN_1.all CN_2.all >CN_3.all
../../tecplot/t2t/t2t.e <CN_3.t2t
mv t2t_cum*.tec CN_3_cum.tec
```

Note that the TEPHRA code is run two times to accommodate the two different plume ratio parameter values. A third output file is created by combining the output of the two single eruption runs. This third output file is the one that is input to the postprocessor to provide a cumulative data set for analysis and plotting. The input for the postprocessor is given in Table 6.18-8.

Table 6.18-8. *t2t.e* Postprocessor Input File *CN_3.t2t*

```
! Input file for program t2t.f90
!
TECPLOT_TITLE
  'Cerro Negro 7-step Wind Field'
!
LABEL_1
  ' Validation Run 7-step Wind Field - Plume Ratio = 0.75'
!
LABEL_2
  ' Eruption = CN_1.erupt'
!
LABEL_3
  ' Grid = basecase.grid'
!
LABEL_4
```

Table 6.18-8. *t2t.e* Postprocessor Input File *CN_3.t2t* (continued)

```
  ' Wind = CN.wind'
!
TEPHRA_OUTPUT_FILE
  'CN_1.all'
!
HEIGHT_PER_GRID_POINT_FILE
  'basecase.height'
!
MODE(individual;cumulative)
  'individual'
!
COORDINATE_SYSTEM(rectangular;cylindrical)
  'rectangular'
!
EOLIAN_AREA_LOWER_LEFT(x,y)
  505000, 1370000
!
EOLIAN_AREA_UPPER_RIGHT(x,y)
  535000, 1390000
!
ERUPTION_RANGE(start,stop)
  1,1
!
ERUPTIONS_IN_FILE
  1
!
DENSITY_COEFFICIENTS
 599.4,  865.6,  -3.66e-4
!
POINT_OF_INTEREST(UTM)
 532370.0, 1382530.0
!
! END
```

Test Results

An isopach map based on measured values for tephra thickness was used to compare with the thicknesses calculated from the TEPHRA Version 1.0 code. Cerro Negro activity from November 19–25, 1995, resulted in tephra deposits that were restricted to within about 5 km [3.1 mi] of the vent and represented about 19–32 percent of the total fall deposit section (Hill, et al., 1998). Measured tephra thicknesses and the isopach map are based on the total tephra deposited. Because this earlier activity and tephra deposition was not modeled, comparisons are not made within a distance of 5 km [3.1 mi] from the vent. Figure 6.18-2 shows the isopachs of tephra thickness and TEPHRA Version 1.0 results with a 5-km [3.1-mi] radial exclusion zone around the vent.

Quantitative comparisons of measured and calculated thicknesses were performed at 1- by 1-km [0.62- by 0.62-mi] grid intervals located outside of the 5-km [3.1-mi] exclusion zone and within the 0.5-cm [0.2-in] isopach. Measured thicknesses were approximated by visually interpolating from the isopach map, and thus, use of one significant digit for quantitative comparison metrics is appropriate.

TEPHRA Version 1.0 slightly underestimated tephra thicknesses in distal regions farther than 10 km [6.2 mi] from the vent. The average percentage difference was about −10 percent over the distal comparison points. On average, modeled tephra deposits differed by about 50 percent (average of the absolute values of percentage differences) from distal estimates of measured thickness. Overall, differences were generally within a factor of 2. Maximum differences (underestimation by factors of about 5 to 10) occurred at 6 point locations on the lobe of the measured isopach directly west from the vent, which was off axis from the single predominant wind direction modeled in TEPHRA Version 1.0.

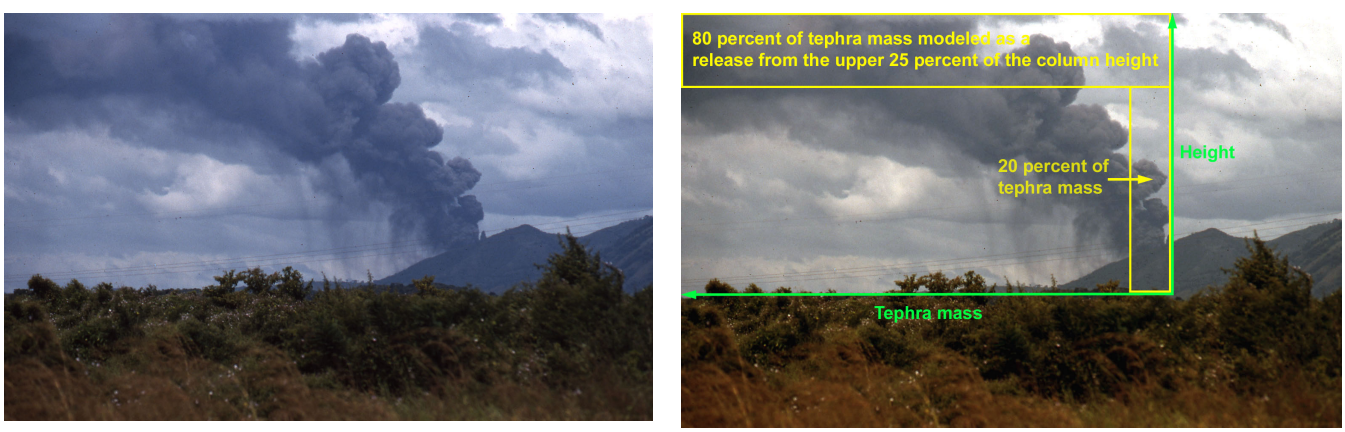
Modeled tephra deposits were generally overestimated in medial regions between 5 and 10 km [3.1 and 6.2 mi] from the vent. The average percentage difference was about 70 percent. On average, modeled tephra deposits differed by 130 percent (average of the absolute values of percentage differences). Differences were mostly within a factor of about 3 for 70 percent of the points but sometimes increased to within a factor of 5 for the remaining 30 percent of the points. As previously discussed, a comparison of proximal deposit thickness was precluded by the 5-km [3.1-mi] exclusion zone.

Given that dynamic eruption characteristics and atmospheric conditions were simplified in specifying inputs for the TEPHRA Version 1.0 simulations, TEPHRA Version 1.0 appears to produce reasonable results.

The TEPHRA code does not explicitly model complex eruption column physics, which can be attributed to some of the differences between modeled tephra deposits and measured deposits. The treatment of the eruption column as a vertical line source represents a simplification, and fits to distal data should be emphasized when evaluating computed versus observed tephra dispersal. Tephra deposition from column and plume fallout is also difficult to model because wind direction and velocity—including variation over time and with change in altitude—are only known to a first-order approximation.

Test Rating

Pass



(a) **(b)**

Figure 6.18-1. (a) Sustained Tephra Eruption on November 30, 1995, as Photographed by B. Hill (Used With Permission) From a Location 37 km [23 mi] South of the Vent; (b) Modeled Distribution of Tephra Mass Within the Eruption Column

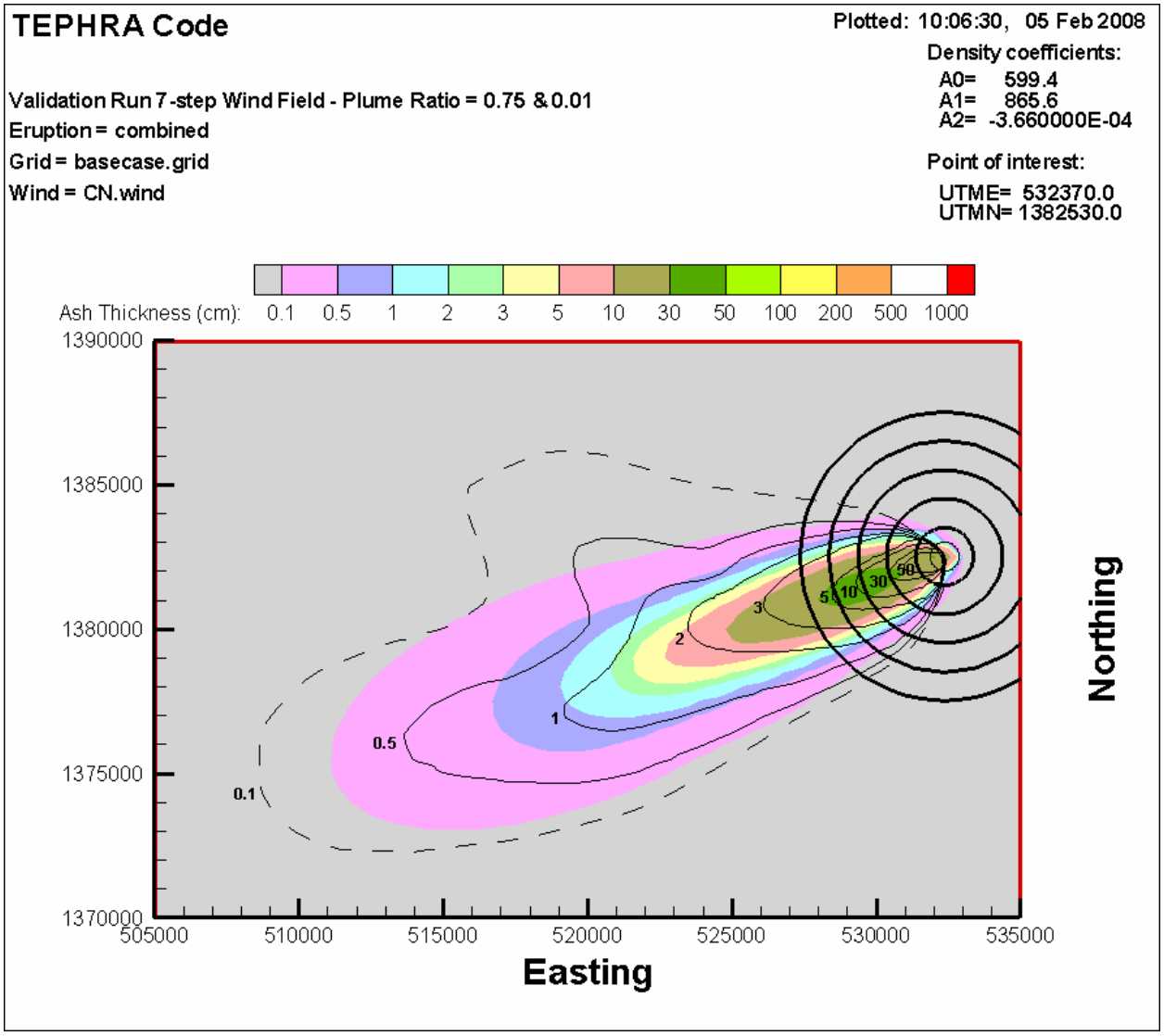


Figure 6.18-2. TEPHRA Version 1.0 Results of Ash Thickness (Color Coded, Legend Values in Centimeters) for the Late-Phase Sustained Tephra Eruption From Cerro Negro in 1995. Isopachs From Thickness Measurements Are Shown by Thin Solid Lines and a Dashed Line for the Provisional Outer Estimate, for Which Ash Thickness Values in Centimeters Are Displayed Within the Plot. Bold Concentric Circles Specify the 5-km [3.1-mi] Exclusion Zone Around the Vent, Where Numerical Comparisons Are Not Performed. (*CN_3_Jan28.tif)*

7 SUMMARY

The TEPHRA code is a volcanic ash transport and deposition model, with waste incorporation, resulting from the erupted ash and waste of a volcanic vent. This report presents the successful validation of the code based on the most commonly used control parameters and the intended use of the code. Seventeen tests, including a ground truth study, were described and the results were presented in graphical form. These tests help ensure that the sense and scale of the output response is appropriate and that the code is functioning properly.

8 REFERENCES

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