TError

User manual

v 1.0

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1 Introduction

The *TError* package was developed to provide a framework to systematically assess how the uncertainty related to the study of tephra deposits affects the Eruption Source Parameters (ESP) commonly quantified to characterize explosive eruptions (i.e. plume height, Mass Eruption Rate (MER), volume). The *TError* package contains two main section. Once the relevant input parameters have been estimated, the first section (i.e. *TError_sensitivity.m*) allows the user to visualize the impact of variations of input parameters on the resulting values of ESP. In the second section (i.e. *TError_propagation.m*), the user defines a maximum error and an error distribution for each input parameter. Through Monte-Carlo simulations, the code then propagates the error distribution of each input parameter through the different ESP. In terror, the terms *error*, *uncertainty* and *noise* are used as synonyms, i.e. describing a variability around a reference value.

2 Running TError

TError was written under *Matlab 2013a*. The main folder contains two .m files:

- *TError_sensitivity.m*: Sensitivity of ESPs to the uncertainty of input parameters
- *TError_propagation.m*: Propagation of distribution of errors of input parameters to all ESPs.

In addition, two folders are also present including:

- *dep*: Dependencies to the code, including all functions used in the main code;
- *Output*: Output folder.

2.1 Inputs

TError requires the user to input parameters related to the compilation of isopleth and isopach maps and to the different models used for the characterization of ESPs. Before running the code, it is necessary to define an error distribution that will be applied on all variable parameters. In *TError*, both Gaussian and uniform distributions are implemented. For each variable parameter, the user needs to define a relative error in percents. If the Gaussian distribution is chosen, the error will represent the 3σ of the distribution. If the uniform distribution is chosen, the error will represent the lower and upper bounds. The input parameters used in *TError* are:

General

- *run_nm*: Run name
- *vent_ht:* Vent height (m asl)
- *trop_ht:* Tropopause height (m asl)
- *nb_sims:* Number of runs of Monte Carlo simulations
- *error_d:* Error distribution: **1** Uniform
  2 Gaussian
- *rangeE:* Error vector for the sensitivity analysis, entered as [min_error : interval : max_error]

Plume height, wind speed

- *cl_d:* Clast density used for the compilation of isopleth maps, invariable in *TError*
- *dm_v:* Maximum clast diameter (cm) associated with the isopleth contours in Carey and Sparks (1986)
- *dm_e:* Error on clast diameter (%)
- *dw_v:* Downwind range (km) as defined in Carey and Sparks (1986)
- *dw_e:* Error on downwind range (%)
- *cw_v:* Crosswind range (km) as defined in Carey and Sparks (1986)
- *cw_e:* Error on crosswind range (%)

Mass eruption rate

- *cstWW_v:* Constant of Wilson and Walker (1987)
- *cstWW_e:* Error on constant of Wilson and Walker (1987) (%)
- *cstMa_v:* Constant of Mastin et al. (2009)
- *cstMa_e:* Error on constant of Mastin et al. (2009) (%)
- *wind_v:* Maximum wind speed at the tropopause (m/s). Enter **-1** to propagate the wind from Carey and Sparks (1986)
- *wind_e:* Error on maximum wind speed (%)

Volume

- *fl:* File containing isopach data, further described later. Should be located in the same folder as the main *TError* scripts. An example of isopach data is given by the file *isopach_example.txt*
- *C_v:* Distal integration limit (km) of Bonadonna and Houghton (2005)
- *C_e:* Error on distal integration limit (%)
- *lam_r:* Initial range of λ for the method of Bonadonna and Costa (2012), entered as $[\lambda_{min}, \lambda_{max}]$
- *lam_r:* Initial range of *n* for the method of Bonadonna and Costa (2012), entered as $[n_{min}, n_{max}]$

Mass

- *dep_d_v:* Bulk deposit density (kg/m^3)
- *dep_d_e:* Error on bulk deposit density (%)

Plot

- *plt:* Enter **1** to produce plots, else **0**
- *frmt:* Format for saving the plots (e.g. *.eps, .png*)
- *max_err:* Maximum range of error to plot, further described later.

Report

- *pcile:* Percentiles to be included in the report. Pairs of percentiles should be symmetrical

In order to allow for a variable uncertainty in the thickness measurement with distance from the vent, input parameters related to the calculation of the tephra volume are input as a separate file, which should be tab-delimited. Table 1 illustrates how the file should be structured.

2			
100	10	49.6	10
50	10	79.2	10
30	10	150.8	10
20	10	301.3	10
10	10	456.0	10
5	10	647.8	10

Table 1: Illustration of an input file for volume calculation

In detail, the table should be structured as follow:

- *Row 1:* Locations of the break in slopes for the volume calculation using the exponential methods.
- *Column 1:* Deposit thickness (cm)
- *Column 2:* Error on deposit thickness (%)
- *Column 3:* Area of isopach contours (km^2)
- *Column 4:* Error on area (%)

The *TError* package accepts up to 3 segments. Therefore, three case figure are possible:

- *1 segment:* Enter **0** in *row 1, column 1*
- *2 segments:* Enter the location of the break in slope as an index in *row 1, column 1*. In Table 1, the break in slope occurs at a distance of 9.6 km, i.e. 92.16 km^2. Hence the index of 2 suggests that the break in slope occures after the second isopach contour, i.e. at an isopach area comprised between 79.2 and 150.8 km^2.
- *3 segment:* Similarly to the 2-segments case, the index of the break in slope be tween the second and third segments should be entered in *row 1, column 2.*

2.2 Workflow

Figure 1 illustrates the workflow implemented in *TError.* Firstly, the plume height and the wind speed are calculated with the method of Carey and Sparks (1986), which is converted into mass eruption rate (MER) with the methods of Wilson and Walker (1987), Mastin et al. (2009) and Degruyter and Bonadonna (2012). In parallel, the volume is calculated with the methods of Fierstein and Nathenson (1992), Bonadonna and Houghton (2005) and Bonadonna and Costa (2012). Volumes are converted into mass using the bulk deposit density and combined with the MER to estimate the eruption duration.

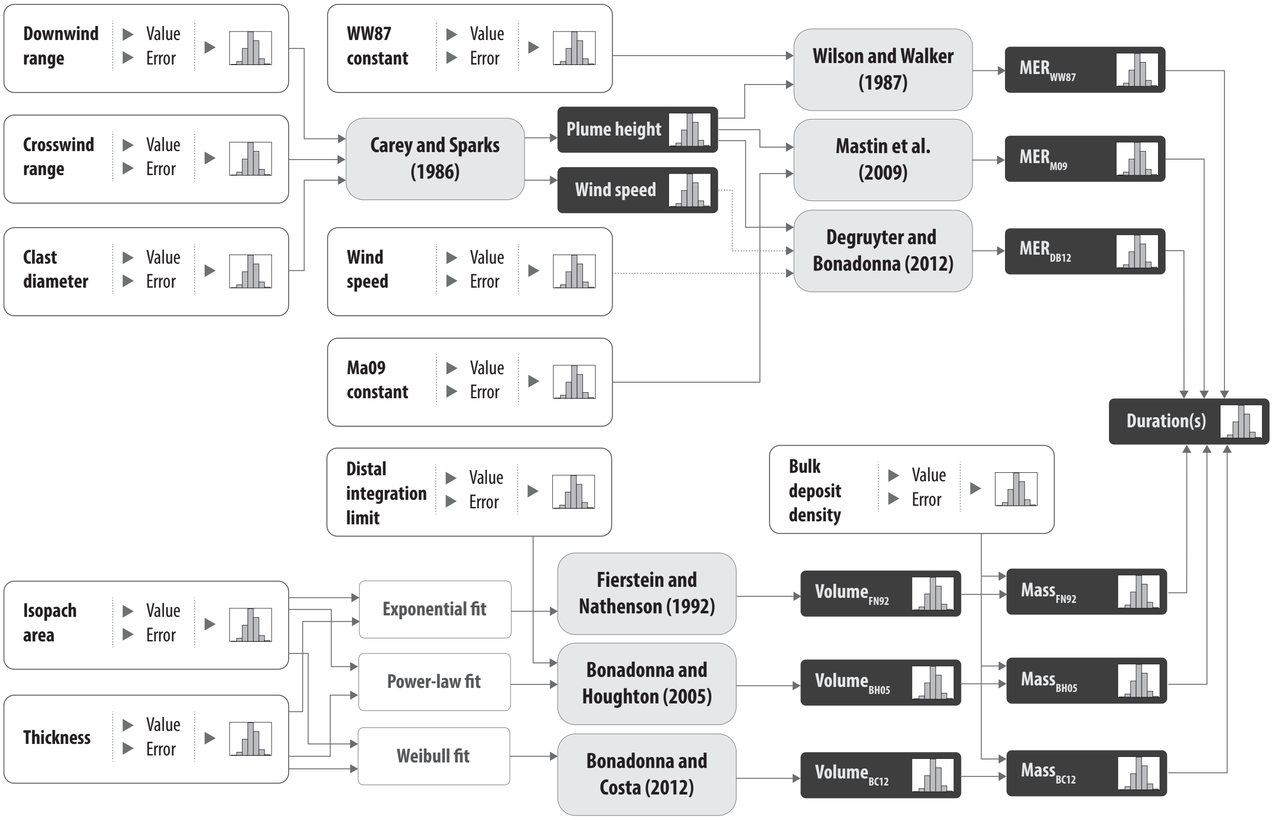

Figure 1: Workflow of *TError*

2.3 Sensitivity analysis

The *TError_sensitivity.m* script helps to systematically investigate the impact of the uncertainty of each input parameter to all ESPs. The *rangeE* variable is a vector containing a succession of relative error, e.g. ranging from -50% to +50% at 5% intervals. This range of errors will be applied to each input parameter separately while keeping the error on other input parameters to 0%, and the workflow of Figure 1 will be applied at each increment.

Once all input parameters have been defined, save your file and type in the main command line:

```
>> TError_sensitivity
```

or click on the *Run* button.

2.4 Error propagation

The *TError_propagation.m* script requires the definition of additional variables. Firstly, *nb_sims* is the number of Monte Carlo simulation the code will run. Secondly, the user must define the type of error distribution (*error_d*) and the maximum ranges of error for each variable parameter (i.e. variable names finishing by *_e*), with the reference values of these variable parameters being defined by variables finishing by *_v*. Throughout the code, each variable parameter will be converted into a distribution of errors (i.e. variable names finishing by *_d*) by stochastic sampling, with the size of the population being equal to *nb_sims*. These distributions of input parameters will then be converted into distributions of ESPs by running the workflow of Figure 1 *nb_sims* times.

Once all input parameters have been defined, save your file and type in the main command line:

```
>> TError_propagation
```

or click on the *Run* button.

3 Outputs

Outputs of both the *TError_sensitivity* and *TError_propagation* scripts comprise a written tabulated summary of the runs and a comprehensive set of figures. All outputs are written in the *Output* folder in a sub-folder named after *run_nm*.

3.1 Sensitivity analysis

The *TError_sensitivity* code produces an *Excel* file comprising as many sheets as error steps contained in the *rangeE* vector. Each sheet comprises a matrix where the columns are the different input parameters and the rows are the different ESPs.

	Downwind range	**Crosswind range**	**Diameter**
Height (CS86)	0	-14	-5
Wind (CS86)	-58	53	-5
MER (WW87)	0	-44	-19
MER (Ma09)	0	-46	-20
MER (DB12)	-30	-36	-25

Table 2: Sensitivity results for an error on input parameters of -25%

Table 2 illustrates a fragment of the *Excel* output file for an error on input parameters of -25%, and shows how, for example, an underestimation of -25% on the downwind range results in underestimations of the wind speed and the MER calculated with the method of Degruyter and Bonadonna (2012) of -58% and -30%, respectively.

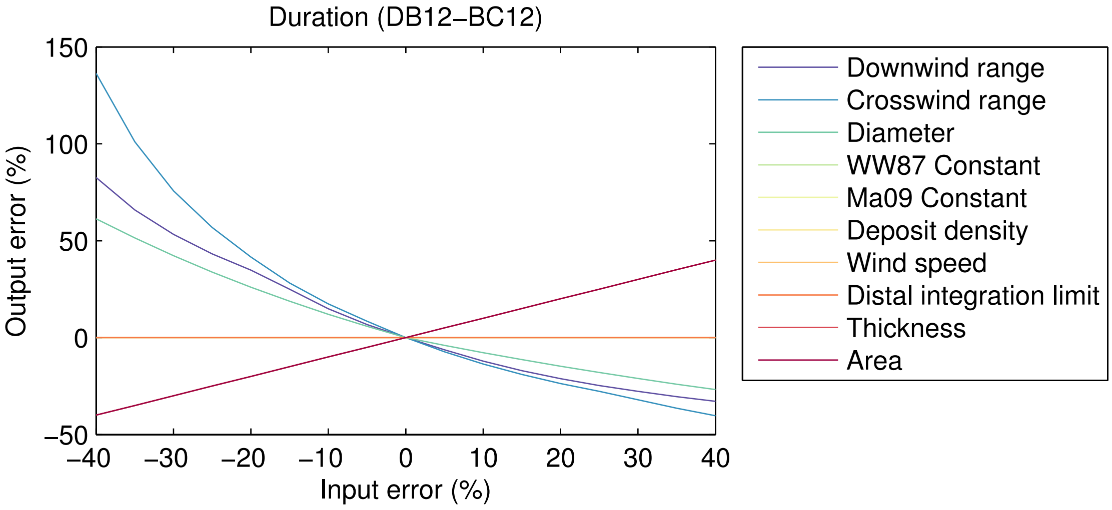

Figure 2: Sensitivity output for the calculation of the duration using the MER from Degruyter and Bonadonna (2012) and the volume from Bonadonna and Costa (2012)

Figure 2 illustrates a typical figure resulting from a *TError_sensitivity* run. The x-axis shows the error on input parameter and the y-axis the error on the selected ESP. This example shows a positive linear dependency of the ESP to the uncertainties on thickness measurements and area of isopach contours and a non-linear negative dependency to downwind range, crosswind range and clast diameter.

3.2 Error propagation

The *TError_propagation* script produces a text file summarizing the distributions of ESPs resulting from the error propagation as illustrated in Table 3.

Out\In	Input value	Median	Minimum	25th%	75th%	Maximum
Plume height	29.5	29.5	27.5	29.1	29.8	31.6
(km asl)			-6.7%	-1.2%	1.2%	7.3%
Wind speed	18.7	18.8	11.4	17.5	20	26.5
(ms-1)			-39.2%	-6.5%	6.9%	41.4%
MER - WW87	4.0E+07	4.0E+07	1.9E+07	3.6E+07	4.5E+07	7.5E+07
(kgs-1)			-52.0%	-10.2%	11.9%	88.0%
MER - Ma09	6.9E+07	6.9E+07	3.8E+07	6.1E+07	7.6E+07	1.5E+08
(kgs-1)			-44.4%	-10.6%	11.2%	112.3%
MER - DB12	1.8E+08	1.8E+08	1.3E+08	1.7E+08	1.9E+08	2.5E+08
(kgs-1)			-29.1%	-4.9%	4.9%	34.3%

Table 3: Summary of a propagation run for selected ESPs. Wind speed is at tropopause.

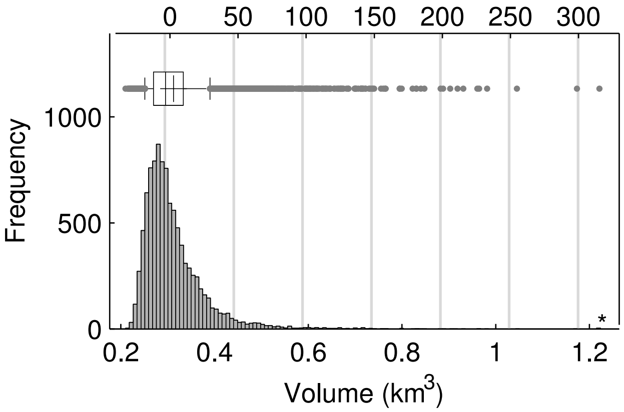

Figure 3: Typical output of the *TError_propagation* code.

The example depicted in Table 3 only serves as an illustration as the entire output contains additional statistical descriptions of the resulting distributions of ESPs. Each ESP is characterized both in absolute and relative terms, where the absolute errors are obtained by normalizing the distributions over the median value. Along with the tabulated output, the *TError_propagation* code also prints out a comprehensive set of figures, where Figure 3 illustrates a typical output.

The main features of this type of figures are:

- The distribution of ESP
- The relative uncertainty (bottom x-axis)
- The absolute uncertainty (top x-axis)
- A box and whiskers plot, where the box represents the 25th and 75th percentiles, the median (vertical line inside the box) and the mean (cross) and the whiskers represent the 9th and 91st percentiles. Dots outside the whiskers are outliers.

In the case extreme values distort the distribution, it is possible to specify the maximum relative error to represent on these plots (i.e. *max_err* variable). Values outside the *max_err* range will be included in the last bin of the probability density plot and a flag (i.e. star on Figure 3) will appear.

4 Functions description

4.1 Main functions

- *TError_sensitivity.m*: Main script for sensitivity analysis
- *TError_propagation*: Main script for error propagation

4.2 Dependencies

- *bc2012.m*: Weibull fit
- *bh2005.m*: Power-law fit
- *fminsearchbnd.m:* Optimization script for the Weibull fit. Written by John D’Errico, http://www.mathworks.com/matlabcentral/fileexchange/8277
- *fn1992.m*: Exponential fit

- *get_height_CS86.m*: Calculation of plume height and wind speed with the method of Carey and Sparks (1986)
- *get_MER_DB12.m*: MER calculation with the method of Degruyter and Bonadonna (2012)
- *get_MER_M09.m*: MER calculation with the method of Mastin et al. (2009)
- *get_MER_WW87.m*: MER calculation with the method of Wilson and Walker (1987)
- *get_vol_BC12.m*: Volume calculation with the method of Bonadonna and Costa (2012)
- *get_vol_BH05*: Volume calculation with the method of Bonadonna and Houghton (2005)
- *get_vol_FN92.m*: Volume calculation with the method of Fierstein and Nathenson (1992)
- *get_WBL_ranges.m*: Sets the ranges of λ and n for the optimization algorithm used for the Weibull fit
- *linspecer.m*: Readable color map. Written by Jonathan Lansey, http://www.mathworks.com/matlabcentral/fileexchange/42673
- *nhist.m*: Function used in the plotting of the *TError_propagation* results. Written by Jonathan Lansey, http://www.mathworks.com/matlabcentral/fileexchange/27388
- *plot_fits_seps.m*: Plot all volume fits performed during the Monte Carlo simulations separately
- *plot_fits.m*: Plot the fits obtained with reference values of thickness measurements and areas of isopach contours
- *plot_results.m*: Main function for plotting the results of the *TError_propagation* code
- *prctile.m*: Returns the selected percentile
- *rand_err*: Returns vectors of relative and absolute errors around the reference value
- *writefile.m*: Write the *TError_propagation* report

4.3 Additional functions

In order to export figures, we suggest installing the *export_fig* script by Olivier Woodford. Due to additional dependencies, this script couldn't be natively included in the *TError* package but can be found at this URL: http://www.mathworks.com/matlabcentral/fileexchange/23629. If installed:

- Comment line 72 of *plot_results.m* and uncomment line 73
- Comment line 345 of *TError_sensitivity* and uncomment line 346

5 Known issues

- On Mac OS X, the native *Matlab xlswrite* function can produce errors displayed on the main commend line, but the report seems to be normally printed.
- Older *Matlab* versions do not accept the definition of transparent variably using "~", in which case search and replace the tilde by a *dummy* name.

6 References

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- Carey S, Sparks R (1986) Quantitative models of the fallout and dispersal of tephra from volcanic eruption columns. Bull Volcanol 48:109–125.

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- Fierstein J, Nathenson M (1992) Another look at the calculation of fallout tephra volumes. Bull Volcanol 54:156–167.

- Mastin L, Guffanti M, Servranckx R, et al. (2009) A multidisciplinary effort to assign realistic source parameters to models of volcanic ash-cloud transport and dispersion during eruptions. J Volcanol Geotherm Res 186:10–21.

- Wilson L, Walker G (1987) Explosive volcanic eruptions - VI. Ejecta dispersal in plinian eruptions: the control of eruption conditions and atmospheric properties. Geophys J R Astr Soc 89:657–679.