Ash Dispersal Forecast and Civil Aviation Workshop

Geneva, Switzerland, 18-20 October 2010

Model Definition Document

Introduction

Volcanic Ash Transport and Dispersion Models (VATDM) can be based on different formulations (Eulerian, Lagrangian or Hybrid), each approach being useful for different applications. In addition, different models might use different parameterizations of different physical processes (e.g., source term, diffusion, sedimentation) and might be designed for specific applications (e.g., local to global coverage). Model performance strictly relies on the original model assumptions and should not be pushed beyond associated application limits. As a result, a critical analysis of individual VATDM is necessary in order to carry out rigorous and robust ash dispersal modelling (reconstruction of past events, forecasting, hazard assessments).

As part of the Ash dispersal forecast and civil aviation workshop this document has been compiled that summarizes main characteristics of most operational and non-operational VATDM currently used (Table 1). Appendices 1 to 12 describe each individual model in detail. The results of the benchmark exercise are presented in the companion *Hekla 2000 Benchmark Document*.

Appendix 1: ASH3D
Appendix 2: ATHAM
Appendix 3: FALL3D
Appendix 4: FLEXPART
Appendix 5: HYSPLIT
Appendix 6: JMA
Appendix 7: MLDP0
Appendix 8: MOCAGE
Appendix 9: NAME
Appendix 10: PUFF
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Appendix 12: VOL-CALPUFF

	ASH3D	ATHAM	FALL3D	FLEXPART	HYSPLIT	JMA	MLDP0	MOCAGE	NAME	PUFF	TEPHRA2	VOL-CALPUFF
Operational	■		■	■	■	■	■	■	■	■	■	■
Approach (1)	E/H	E	E	L	H	L	L	E	L	L	E	H
Method (2)	N	N	N	N	N	N	N	N	N	N	A	S
Coverage (3)	LRG	L	LR	LRG	LRG	G	LRG	G	LRG	LRG	L	LR
Physics												
Topography		■	■	■	■	■	■	■	■	■	■	■
H wind advection	■	■	■	■	■	■	■	■	■	■	■	■
V wind advection	■	■	■	■	■	■	■	■	■	■		■
H atm. diffusion	■	■	■	■	■	■	■	See (5)	■	■	■	■
V atm. diffusion	■	■	■	■	■	■	■	■	■	■		■
Particle sed.	■	■	■	■	■	■	■	■	■	■	■	■
Other dry dep.			■	■	■	■		■	■			
Wet deposition				■	■	■	■	■	■			■
Dry part. aggr.												
Wet part. aggr.			■									
Particle shape	■		■		■		■					■
Gas species		■	■	■	■			■	■			■
Chemic. processes				■	■				■			■
Granulometry												
Variable size class.	■	■	■	■	■		■	■	■	■	■	■
Variable GS distr.	■		■	■	■				■			■
Variable size limits	■	■	■	■			■		■	■	■	■
Source term												
Mass distribution(4)	LN	O	ALL	PS/L/U/P/O	PS/L/U/P/LN	PS/L/U/P/LN	PS/L/U/LN	PS/L	PS/L/O	PS/L/U/P	L/U/LN	PS/BP

(1) L=Lagrangian, E=Eulerian, H=Hybrid
(2) A=Analytical, S=Semi-analytical, N=Numerical
(3) L=Local, R=Regional, G=Global
(4) PS=Point Source, L=Linear, U=Umbrella-type, P=Poisson, LN=Log-normal, BP=Buoyant Plume, O= Other (see Appendix).
(5) Neglected. Diffusion of numerical origin appears to be sufficient, with particularly good results at 0.5°.

Table 1. Main characteristics of VATDM

1. Model overview

Model Name	**Ash3d**	
Approach		Tick
	Eulerian	X
	Lagrangian	
	Hybrid (there is a semi-Lagrange option)	x
Method		Tick
	Analytical (e.g. Gaussian)	
	Semi-analytical	
	Numerical	x
Model coverage		Tick
	Local (order of 100s of km)	x
	Regional (order of 1000s of km)	x
	Global (globe coverage, periodicity)	x

	YES	NO
Is the horizontal spatial resolution fixed?		x
Is the vertical spatial resolution fixed?		x
Is it operational for forecast at some Institution/VAAC/VO?		x

2. Model physics

Please, specify if the model accounts for the following parameters/processes:

	Tick	Comments
Topography		
Horizontal wind advection	x	
Vertical wind advection	x	
Horizontal atmospheric diffusion	x	
Vertical atmospheric diffusion	x	
Particle sedimentation	x	
Other dry deposition mechanisms		
Wet deposition (wet removal)		
Dry particle aggregation		
Wet particle aggregation		
Particle shape	x	
Dispersal of different gas species		
Chemical processes		
Others		

3. Particle granulometry

	YES	NO	Comments
Is the number of classes (bins) fixed?		x	
Is the granulometric distribution arbitrary?	X		
Is there an upper/lower limit on the particle size?		x	

4. Meteorological data

	Tick	Comments
On-line coupling		
Off-line coupling	x	

	YES	NO
Is the model linked to a particular NWP model?		x
Is there some pre-process interface for NWP data interpolation?	x	

If the model can assimilate meteorological data from different NWP models or meteorological datasets, please specify which ones:
NOAA North American Models: Grid 216 (Alaska 45 km), Awips Grid 218 (Alaska CONUS 12 km), Global Forecasts System (GFS) high-resolution, 0.5° to date.

Please specify the meteorological variables required:
vx, vy

5. Eruptive column (source term)

Please specify which of the following options are possible for describing the mass (concentration) distribution along the eruptive column

	Tick	Comments
Point source		
Uniform (linear) vertical distribution		
Umbrella-type (top-hat)		
Poisson distribution		
Log-normal (Suzuki) distribution (e.g. Suzuki 1983; Armienti et al. 1988)	x	
Buoyant plume theory		
Others		

	YES	NO
Can transient columns be described?	x	
Can data (e.g. from satellite retrievals) be assimilated as an "initial" source term condition?		x

6. Model outputs

Please specify if the model outputs the following variables (or, in case it just outputs a primary variable – mass, concentration, puff or particle location, etc – if it exists a postprocess utility to compute them):

	Tick	Comments
Tephra deposit load		
Tephra deposit thickness	x	

Airborne concentration	x	
Airborne concentration profiles (e.g. at a given height or flight level)	x	3-d ash cloud structure can be written out.
Vertical concentration profiles	x	
Aerosol optical depth		
Aerosol (gas) concentration		
Cloud mass	x	
Cloud area/volume	x	
Concentration at ground level		
Others	x	Ash arrival times at airports

Please specify the model output format

	Tick	Comments
ASCII	x	
Binary (exclusive of the model)	x	
netCDF	x	
Grib1		
Grib2		
Graphic format (e.g, eps, gif)		
Others	x	Kml format

7. Computational characteristics

Programming language	Fortran 95		
Operating system	Mostly Linux (there is a Windows version)		
		YES	NO
Does a parallel version of the code exist?			x
Is it an open source/public code? (eventually, yes)			
External library packages:			
Regridpack, Lapack, NetCDF, Proj4			

8. Others

References
The model will be documented in two articles in the upcoming special issue of *Atmospheric Environment*.
Other comments
Coding for this model was only started in January, 2010. Many features are still being added, and much testing is still being done.

1. Model overview

Model Name	**ATHAM**	
Approach		Tick
	Eulerian	✓
	Lagrangian	
	Hybrid	
Method		Tick
	Analytical (e.g. Gaussian)	
	Semi-analytical	
	Numerical	✓
Model coverage		Tick
	Local (order of 100s of km)	✓
	Regional (order of 1000s of km)	
	Global (globe coverage, periodicity)	

	YES	NO
Is the horizontal spatial resolution fixed?		✓
Is the vertical spatial resolution fixed?		✓
Is it operational for forecast at some Institution/VAAC/VO?		✓

2. Model physics

Please, specify if the model accounts for the following parameters/processes:

	Tick	Comments
Topography	✓	
Horizontal wind advection	✓	
Vertical wind advection	✓	
Horizontal atmospheric diffusion	✓	
Vertical atmospheric diffusion	✓	
Particle sedimentation	✓	
Other dry deposition mechanisms		
Wet deposition (wet removal)	☑	part of the (currently not supported) wet aggregation scheme
Dry particle aggregation		
Wet particle aggregation	☑	currently not supported in most recent version
Particle shape		
Dispersal of different gas species	✓	
Chemical processes		
Others	☑	Scavenging of volcanic gases by hydrometeors; currently not supported in most recent version

3. Particle granulometry

	YES	NO	Comments
Is the number of classes (bins) fixed?		✓	
Is the granulometric distribution arbitrary?		✓	
Is there an upper/lower limit on the particle size?		✓	No hard limit, however, the assumptions of a dynamical and thermodynamical equilibrium start to break down for particles larger than a few millimetres.

4. Meteorological data

	Tick	Comments
On-line coupling	✓	Starting from initial conditions the model predicts all meteorological fields.
Off-line coupling		

	YES	NO
Is the model linked to a particular NWP model?		✓
Is there some pre-process interface for NWP data interpolation?		✓

If the model can assimilate meteorological data from different NWP models or meteorological datasets, please specify which ones:

Please specify the meteorological variables required:
Only initial vertical profiles for temperature, humidity and horizontal wind are required. The model is initialised horizontally homogeneously assuming an initial hydrostatic balance.

5. Eruptive column (source term)

Please specify which of the following options are possible for describing the mass (concentration) distribution along the eruptive column

	Tick	Comments
Point source		
Uniform (linear) vertical distribution		
Umbrella-type (top-hat)		
Poisson distribution		
Log-normal (Suzuki) distribution (e.g. Suzuki 1983; Armienti et al. 1988)		
Buoyant plume theory		

Others	✓	Atham simulates the eruption column and plume based on a prescribed volcanic forcing at the lower boundary (vent).

	YES	NO
Can transient columns be described?	✓	
Can data (e.g. from satellite retrievals) be assimilated as an "initial" source term condition?		✓

6. Model outputs

Please specify if the model outputs the following variables (or, in case it just outputs a primary variable – mass, concentration, puff or particle location, etc – if it exists a postprocess utility to compute them):

	Tick	Comments
Tephra deposit load	✓	
Tephra deposit thickness	✓	
Airborne concentration	✓	
Airborne concentration profiles (e.g. at a given height or flight level)	✓	
Vertical concentration profiles	✓	
Aerosol optical depth		
Aerosol (gas) concentration	✓	
Cloud mass	✓	
Cloud area/volume	✓	
Concentration at ground level	✓	
Others		

Please specify the model output format

	Tick	Comments
ASCII		
Binary (exclusive of the model)	✓	Optional
netCDF	✓	Optional
Grib1		
Grib2		
Graphic format (e.g, eps, gif)		
Others		

7. Computational characteristics

Programming language	Fortran 90		
Operating system	Linux		
		YES	NO

Does a parallel version of the code exist?	✓	
Is it an open source/public code? The code is available through collaboration.	✓	✓
External library packages:		

8. Others

References
Herzog M. and H.-F. Graf (2010): Applying the three-dimensional model ATHAM to volcanic plumes: Dynamic of large co-ignimbrite eruptions and associated injection heights for volcanic gases, Geophys. Res. Let. in print Tupper A., C. Textor, M. Herzog, H.-F. Graf, and M. S. Richards (2009): Tall clouds from small eruptions: the sensitivity of eruption height and fine ash content to tropospheric instability, Nat. Hazards, 51, pp. 375-401, doi 10.1007/11069-009-9433-9. Textor C., H. F. Graf, M. Herzog, J. M. Oberhuber, W. I. Rose, G. G. J. Ernst (2006): Volcanic Particle Aggregation in Explosive Eruption Columns. Part I: Parameterization of the Microphysics of Hydrometeors and Ash. J. Volcanl. Geotherm. Res., Vol. 150, pp. 359-377. Textor C., H. F. Graf, M. Herzog, J. M. Oberhuber, W. I. Rose, G. G. J. Ernst (2006): Volcanic Particle Aggregation in Explosive Eruption Columns. Part II: Numerical Experiments. J. Volcanl. Geotherm. Res., Vol. 150, pp. 378-394. Herzog M., J. M. Oberhuber, Hans-F. Graf (2003): A Prognostic Turbulence Scheme for the Non-hydrostatic Plume Model ATHAM. J. Atmos. Sci. 60(22), pp. 2783-2796. Textor C., H.-F. Graf, M. Herzog (2003): Injection of Gases into the Stratosphere by Explosive Volcanic Eruptions. J. Geophys. Res. 108(D19): 4606, doi: 10.1029/2002JD002987. Graf, H.-F., M. Herzog, J. M. Oberhuber (1999): The Effect of Environmental Conditions on Volcanic Plume Rise. J. Geophys. Res., Vol. 104, pp. 24,309-24,320. Herzog M., H.-F. Graf, C. Textor, J. M. Oberhuber (1998): The effect of Phase Changes of Water on the Development of Volcanic Plumes. J. Volcanl. Geotherm. Res., Vol. 87, pp. 29-53. Oberhuber, J. M., M. Herzog, H.-F. Graf, K. Schwanke (1998): Volcanic Plume Simulation on Large Scales. J. Volcanl. Geotherm. Res., Vol. 87, pp. 55-74.
Other comments

1. Model overview

Model Name	**FALL3D**	
Approach		Tick
	Eulerian	✓
	Lagrangian	
	Hybrid	
Method		Tick
	Analytical (e.g. Gaussian)	
	Semi-analytical	
	Numerical	✓
Model coverage		Tick
	Local (order of 100s of km)	✓
	Regional (order of 1000s of km)	✓
	Global (globe coverage, periodicity)	

	YES	NO
Is the horizontal spatial resolution fixed?		✓
Is the vertical spatial resolution fixed?		✓
Is it operational for forecast at some Institution/VAAC/VO?	✓	

2. Model physics

Please, specify if the model accounts for the following parameters/processes:

	Tick	Comments
Topography	✓	
Horizontal wind advection	✓	
Vertical wind advection	✓	
Horizontal atmospheric diffusion	✓	
Vertical atmospheric diffusion	✓	
Particle sedimentation	✓	Different experimental laws available
Other dry deposition mechanisms	✓	Dry deposition mechanism different form sedimentation velocity only for particles smaller than 100 μm (below the limit of the aerosol giant mode) and in the first layer See: J.Feng, A size-resolved model and a four-mode parameterization of dry deposition of atmospheric aerosols, JGR, v113, 2008.
Wet deposition (wet removal)		
Dry particle aggregation		
Wet particle aggregation	✓	(Under test).
Particle shape	✓	
Dispersal of different gas species	✓	Gas species are approached as particles with no settling velocity
Chemical processes		
Others		

3. Particle granulometry

	YES	NO	Comments
Is the number of classes (bins) fixed?		✔	
Is the granulometric distribution arbitrary?	✔		A utility is given to generate Gaussian and bi-Gaussian (bi-modal) distributions
Is there an upper/lower limit on the particle size?		✔	Not recommended above 32-64 mm and below 1 μm

4. Meteorological data

	Tick	Comments
On-line coupling		
Off-line coupling	✔	

	YES	NO
Is the model linked to a particular NWP model?		✔
Is there some pre-process interface for NWP data interpolation?	✔	

If the model can assimilate meteorological data from different NWP models or meteorological datasets, please specify which ones:
ECMWF re-analysis, ETA, WRF-ARW, GFS (0.5º and 1º), ARPA-SIM, NMM-b, NCEP/NCAR re-analysis (2.5º and 1º), CALMET, vertical profile (e.g. from sounding).

Please specify the meteorological variables required:
2D: Land use (optional), Planetary Boundary Layer height (optional), Friction velocity u* , Monin-Obukhov length. 3D: wind velocity, temperature, air density, and potential temperature and specific humidity if wet aggregation is considered.

5. Eruptive column (source term)

Please specify which of the following options are possible for describing the mass (concentration) distribution along the eruptive column

	Tick	Comments
Point source	✔	
Uniform (linear) vertical distribution		
Umbrella-type (top-hat)		
Poisson distribution		
Log-normal (Suzuki) distribution (e.g. Suzuki 1983; Armienti et al. 1988)	✔	

Buoyant plume theory	✔	
Others		

	YES	NO
Can transient columns be described?	✔	
Can data (e.g. from satellite retrievals) be assimilated as an “initial” source term condition?		✔

6. Model outputs

Please specify if the model outputs the following variables (or, in case it just outputs a primary variable – mass, concentration, puff or particle location, etc – if it exists a postprocess utility to compute them):

	Tick	Comments
Tephra deposit load	✔	
Tephra deposit thickness	✔	
Airborne concentration	✔	
Airborne concentration profiles (e.g. at a given height or flight level)	✔	
Vertical concentration profiles	✔	
Aerosol optical depth	✔	
Aerosol (gas) concentration	✔	
Cloud mass		
Cloud area/volume		
Concentration at ground level	✔	
Others	✔	PMx at surface

Please specify the model output format

	Tick	Comments
ASCII		
Binary (exclusive of the model)		
netCDF	✔	
Grib1		
Grib2		
Graphic format (e.g, eps, gif)		
Others	✔	GRD format optional

7. Computational characteristics

Programming language	FORTRAN 90		
Operating system	UNIX/LINUX		
		YES	NO
Does a parallel version of the code exist?		✔	
Is it an open source/public code?		✔	
External library packages:			
netCDF			

8. Others

References

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

Folch A., O. Jorba, J. Viramonte (2008). Volcanic ash forecast – application to the May 2008 Chaitén eruption, Nat. Hazards Earth Syst. Sci., 8, 927-940.

Scollo, S., A. Folch, A. Costa (2008). A parametric and comparative study of different tephra fallout models,Journal of Volcanology and Geothermal Research, 176, 199–211.

Folch A., C. Cavazzoni, A. Costa, G. Macedonio (2008). An automatic procedure to forecast tephra fallout, Journal of Volcanology and Geothermal Research 177, 767–777.

Macedonio G., A. Costa, A. Folch (2008). Ash fallout scenarios at Vesuvius: Numerical simulations and implications for hazard assessment, Journal of Volcanology and Geothermal Research, 178, 366–377.

Folch A., A. Costa, G. Macedonio (2009). FALL3D: A Computational Model for Volcanic Ash Transport and Deposition, Computer and Geosciences, doi:10.1016/j.cageo.2008.08.008.

Costa A., A. Folch, G. Macedonio (2010). A Model for Wet Aggregation of Ash Particles in Volcanic Plumes and Clouds: I. Theoretical Formulation, J. Geophys. Res., doi:10.1029/2009JB007175.

Folch A.,A. Costa, A. Durant,G. Macedonio (2010). A Model for Wet Aggregation of Ash Particles in Volcanic Plumes and Clouds: II. Model Application, J. Geophys. Res., doi:10.1029/2009JB007176.

Other comments

See http://www.bsc.es/projects/earthscience/fall3d/

1. Model overview

Model Name	**FLEXPART**	
Approach		Tick
	Eulerian	
	Lagrangian	X
	Hybrid	
Method		Tick
	Analytical (e.g. Gaussian)	
	Semi-analytical	
	Numerical	X
Model coverage		Tick
	Local (order of 100s of km)	X
	Regional (order of 1000s of km)	X
	Global (globe coverage, periodicity)	X

	YES	NO
Is the horizontal spatial resolution fixed?		X
Is the vertical spatial resolution fixed?		X
Is it operational for forecast at some Institution/VAAC/VO?	X	

Operational at least at CTBTO and Central Institute for Meteorology, Austria. At the latter also for ash forecasting during Eyjafjallajoekull.

2. Model physics

Please, specify if the model accounts for the following parameters/processes:

	Tick	Comments
Topography	X	
Horizontal wind advection	X	
Vertical wind advection	X	
Horizontal atmospheric diffusion	X	
Vertical atmospheric diffusion	X	
Particle sedimentation	X	
Other dry deposition mechanisms	X	
Wet deposition (wet removal)	X	
Dry particle aggregation		
Wet particle aggregation		
Particle shape		
Dispersal of different gas species	X	
Chemical processes	X	Only SO2 reaction with OH radical
Others	X	Convection

3. Particle granulometry

	YES	NO	Comments
Is the number of classes (bins) fixed?		X	
Is the granulometric distribution arbitrary?		X	
Is there an upper/lower limit on the particle size?		X	

4. Meteorological data

	Tick	Comments
On-line coupling		
Off-line coupling	X	

	YES	NO
Is the model linked to a particular NWP model?		X
Is there some pre-process interface for NWP data interpolation?		X

If the model can assimilate meteorological data from different NWP models or meteorological datasets, please specify which ones:
ECMWF re-analysis (1°×1° horizontal resolution, 91 vertical levels) GFS (0.5°×0.5° horizontal resolution at 26 pressure levels) Different versions exist also for MM5, WRF, etc., but are not used at our institute

Please specify the meteorological variables required:
2D: many 3D: horizontal and vertical wind components, temperature and specific humidity.

5. Eruptive column (source term)

Please specify which of the following options are possible for describing the mass (concentration) distribution along the eruptive column

	Tick	Comments
Point source	X	
Uniform (linear) vertical distribution	X	
Umbrella-type (top-hat)	X	
Poisson distribution	X	
Log-normal (Suzuki) distribution (e.g. Suzuki 1983; Armienti et al. 1988)		

Buoyant plume theory		
Others	X	Detailed vertical ash emission distribution, e.g., from inverse modelling

	YES	NO
Can transient columns be described?	X	
Can data (e.g. from satellite retrievals) be assimilated as an "initial" source term condition? *Not operational but was done in case studies in the past*	X	

6. Model outputs

Please specify if the model outputs the following variables (or, in case it just outputs a primary variable – mass, concentration, puff or particle location, etc – if it exists a postprocess utility to compute them):

	Tick	Comments
Tephra deposit load	X	
Tephra deposit thickness		Should be simple to calculate from the above
Airborne concentration	X	
Airborne concentration profiles (e.g. at a given height or flight level)	X	
Vertical concentration profiles	X	
Aerosol optical depth		
Aerosol (gas) concentration	X	
Cloud mass	X	
Cloud area/volume		Not clear how that would be defined
Concentration at ground level	X	
Others		

Please specify the model output format

	Tick	Comments
ASCII		
Binary (exclusive of the model)	X	
netCDF		
Grib1		
Grib2		
Graphic format (e.g, eps, gif)		
Others		

7. Computational characteristics

Programming language	Fortran		
Operating system	UNIX/LINUX		
		YES	NO
Does a parallel version of the code exist?			X
Is it an open source/public code?		X	
External library packages:			
GRIB decoding library			

8. Others

References
Stohl, A., M. Hittenberger, and G. Wotawa (1998): Validation of the Lagrangian particle dispersion model FLEXPART against large scale tracer experiments. Atmos. Environ. 32, 4245-4264. Stohl, A., and D. J. Thomson (1999): A density correction for Lagrangian particle dispersion models. Bound.-Layer Met. 90, 155-167. Stohl, A., C. Forster, A. Frank, P. Seibert, and G. Wotawa (2005): Technical Note : The Lagrangian particle dispersion model FLEXPART version 6.2. Atmos. Chem. Phys. 5, 2461-2474. Eckhardt, S., A. J. Prata, P. Seibert, K. Stebel, and A. Stohl (2008): Estimation of the vertical profile of sulfur dioxide injection into the atmosphere by a volcanic eruption using satellite column measurements and inverse transport modeling. Atmos. Chem. Phys. 8, 3881-3897.
Other comments
See http://transport.nilu.no/flexpart/

1. Model overview

Model Name	**HYSPLIT**	
Approach		Tick
	Eulerian	
	Lagrangian	
	Hybrid	x
Method		Tick
	Analytical (e.g. Gaussian)	
	Semi-analytical	
	Numerical	x
Model coverage		Tick
	Local (order of 100s of km)	x
	Regional (order of 1000s of km)	x
	Global (globe coverage, periodicity)	x

	YES	NO
Is the horizontal spatial resolution fixed?		X
Is the vertical spatial resolution fixed?		X
Is it operational for forecast at some Institution/VAAC/VO?	X	

2. Model physics

Please, specify if the model accounts for the following parameters/processes:

	Tick	Comments
Topography	X	Resolution of meteorology model
Horizontal wind advection	X	
Vertical wind advection	X	
Horizontal atmospheric diffusion	X	
Vertical atmospheric diffusion	X	
Particle sedimentation	X	
Other dry deposition mechanisms	X	
Wet deposition (wet removal)	X	
Dry particle aggregation		
Wet particle aggregation		
Particle shape	X	Fixed for VAAC simulation
Dispersal of different gas species	X	VAAC simulation only with particles
Chemical processes	X	VAAC assumes no transformation
Others		

3. Particle granulometry

	YES	NO	Comments
Is the number of classes (bins) fixed?		X	Fixed for VAAC simulation
Is the granulometric distribution arbitrary?		X	Fixed for VAAC simulation
Is there an upper/lower limit on the particle size?	X		~ 100 μm for VAAC simulation

4. Meteorological data

	Tick	Comments
On-line coupling		
Off-line coupling	x	

	YES	NO
Is the model linked to a particular NWP model?		X
Is there some pre-process interface for NWP data interpolation?	X	

If the model can assimilate meteorological data from different NWP models or meteorological datasets, please specify which ones:
(assume input rather than assimilate) NCEP GFS, NAM, RUC, Regional Re-analysis, NOAA/GSD HRRR, ECMWF, NCEP/NCAR Reanalysis, and others if they can be formatted to the HYSPLIT/ARL-meteorology-format (basic grib-to-hysplit-format converter program included in HYSPLIT system)

Please specify the meteorological variables required:
Minimum requirement: 3-dimensional winds, temperature, humidity either on pressure, sigma, or hybrid surfaces; surface pressure, 10-m winds, 2-m temperature, precipitation

5. Eruptive column (source term)

Please specify which of the following options are possible for describing the mass (concentration) distribution along the eruptive column

	Tick	Comments
Point source	X	
Uniform (linear) vertical distribution	X	Only this at VAAC
Umbrella-type (top-hat)	X	
Poisson distribution	X	Approximated
Log-normal (Suzuki) distribution (e.g. Suzuki 1983; Armienti et al. 1988)	X	Approximated
Buoyant plume theory		
Others		

	YES	NO
Can transient columns be described?	x	
Can data (e.g. from satellite retrievals) be assimilated as an “initial” source term condition?	X, qualitatively	X, quantitatively

6. Model outputs

Please specify if the model outputs the following variables (or, in case it just outputs a primary variable – mass, concentration, puff or particle location, etc – if it exists a postprocess utility to compute them):

	Tick	Comments
Tephra deposit load	X	(given appropriate GSD, but not the GSD used by the VAAC)
Tephra deposit thickness		
Airborne concentration	X	
Airborne concentration profiles (e.g. at a given height or flight level)		
Vertical concentration profiles		
Aerosol optical depth		
Aerosol (gas) concentration		
Cloud mass		
Cloud area/volume		
Concentration at ground level		
Others	x	Particle positions

Please specify the model output format

	Tick	Comments
ASCII	X	
Binary (exclusive of the model)	X	
netCDF		
Grib1	X	
Grib2		
Graphic format (e.g, eps, gif)	X	ps, gif at VAAC ; GIS shapefile, Google Earth not at VAAC
Others		

7. Computational characteristics

Programming language	FORTRAN90	
Operating system	UNIX/Linux, PC, Apple,	
	YES	NO
Does a parallel version of the code exist?	X	
Is it an open source/public code?	X	
External library packages:		
none		

8. Others

References
Draxler, R.R., and G.D. Hess, 1997: Description of the HYSPLIT_4 modeling system. NOAA Tech. Memo. ERL ARL-224, NOAA Air Resources Laboratory, Silver Spring, MD, 24 pp.

Draxler, R.R., and G.D. Hess, 1998: An overview of the HYSPLIT_4 modeling system of trajectories, dispersion, and deposition. Aust. Meteor. Mag., 47, 295-308.

Draxler, R.R., 1999: HYSPLIT4 user's guide. NOAA Tech. Memo. ERL ARL-230, NOAA Air Resources Laboratory, Silver Spring, MD.

Barbara J.B. Stunder, Jerome L. Heffter, Roland R. Draxler, 2007, Airborne Volcanic Ash Forecast Area Reliability, Weather and Forecasting, 22:1132-1139

Other comments
The model is designed to support a wide range of simulations related to the atmospheric transport and dispersion of pollutants and hazardous materials, as well as the deposition of these materials (such as mercury) to the Earth's surface. Some of the applications include tracking and forecasting the release of radioactive material, volcanic ash, wildfire smoke, dust, and pollutants from various stationary and mobile emission sources. HYSPLIT can be run interactively on ARL's READY (Real-time Environmental Applications and Display sYstem, http://ready.arl.noaa.gov/) web site, or it can be installed on a PC and run using a graphical user interface. Meteorological offset ensemble and associated post-processing programs are included with the HYSPLIT system.

1. Model overview

Model Name	**JMA Global Tracer Transport Model**	
Model Approach		Tick
	Analytical (Gaussian)	
	Numerical (Eulerian)	
	Numerical (Lagrangian)	✓
	Numerical (Hybrid)	
	Other	
Model coverage		Tick
	Local (order of 100s of km)	
	Regional (order of 1000s of km)	
	Global (globe coverage, periodicity)	✓

	YES	NO
Is the horizontal spatial resolution fixed?		✓
Is the vertical spatial resolution fixed?		✓
Is it operational for forecast at some Institution/VAAC/VO?	✓	

2. Model physics

Please, specify if the model accounts for the following parameters/processes:

	Tick	Comments
Topography	✓	depend on NWP model
Horizontal wind advection	✓	
Vertical wind advection	✓	
Horizontal atmospheric diffusion	✓	
Vertical atmospheric diffusion	✓	
Particle sedimentation	✓	as dry deposition
Other dry deposition mechanisms		
Wet deposition (wet removal)	✓	only washout, not rainout
Dry particle aggregation		
Wet particle aggregation		
Particle shape	✓	considered in the settling velocity
Dispersal of different gas species		
Chemical processes		
Others	✓	radioactive decay

3. Particle granulometry

	YES	NO	Comments
Is the number of classes (bins) fixed?	✓		under development, tracer mass allocation with 80 bin numbers
Is the granulometric distribution arbitrary?		✓	under development, using log-normal distribution for grain size
Is there an upper/lower limit on the particle size?	✓		under development, about 0.1 mm upper limit

4. Meteorological data

	Tick	Comments
On-line coupling		
Off-line coupling	✓	JMA Global Spectral Model (JMA-GSM)

	YES	NO
Is the model linked to a particular NWP model?		✓
Is there some pre-process interface for NWP data interpolation?	✓	

If the model can assimilate meteorological data from different NWP models or meteorological datasets, please specify which ones:
(i) JMA-GSM (0.1875°×0.1875°L60, operationally) (ii) Japanese Reanalysis (JRA-25, 1.25°×1.25°L23, for benchmark simulation)

Please specify the meteorological variables required:
wind vector, temperature, specific humidity, pressure, precipitation

5. Eruptive column (source term)

Please specify which of the following options are possible for describing the mass (concentration) distribution along the eruptive column

	Tick	Comments
Point source	✓	option
Uniform (linear) vertical distribution	✓	option
Umbrella-type (top-hat)	✓	default
Poisson distribution		
Log-normal (Suzuki) distribution (e.g. Suzuki 1983; Armienti et al. 1988)	✓	Suzuki 1983
Buoyant plume theory		
Others		

	YES	NO
Can transient columns be described?	✓	
Can data (e.g. from satellite retrievals) be assimilated as an "initial" source term condition?	✓*	

* under development, only volcanic-ash cloud area on satellite imagery

6. Model outputs

Please specify if the model outputs the following variables (or, in case it just outputs a primary variable – mass, concentration, puff or particle location, etc – if it exists a postprocess utility to compute them):

	Tick	Comments
Tephra deposit load	✓	not operational
Tephra deposit thickness		
Airborne concentration	✓	only dispersion area in operation
Airborne concentration profiles (e.g. at a given height or flight level)		
Vertical concentration profiles		
Aerosol optical depth		
Aerosol (gas) concentration		
Cloud mass		
Cloud area/volume		
Concentration at ground level		
Others	✓	trajectory of specific tracers

Please specify the model output format

	Tick	Comments
ASCII		
Binary (exclusive of the model)	✓	
netCDF		
Grib1		
Grib2		
Graphic format (e.g, eps, gif)	✓	
Others		

7. Computational characteristics

Programming language	Fortran90	
Operating system	Linux	
	YES	NO
Does a parallel version of the code exist?		✓
Is it an open source/public code?		✓
External library packages:		
JMA 'NWPLIB', 'NuSDaS'		

8. Others

References
Iwasaki, T., T. Maki and K. Katayama, 1998: Tracer transport model at Japan Meteorological Agency and its application to the ETEX data. Atmos. Environ., 32, 4285–4295.
Other comments
The model is now under development and will be operational at Tokyo VAAC in 2012, therefore there is a possibility of changing the above specifications.

1. Model overview

Model Name	**MLDP0 (Modèle Lagrangien de Dispersion de Particules d'ordre zéro)**	
Approach		Tick
	Eulerian	
	Lagrangian	×
	Hybrid	
Method		Tick
	Analytical (e.g. Gaussian)	
	Semi-analytical	
	Numerical	×
Model coverage		Tick
	Local (order of 100s of km)	×
	Regional (order of 1000s of km)	×
	Global (globe coverage, periodicity)	×
	YES	NO
Is the horizontal spatial resolution fixed? * The horizontal and vertical spatial resolutions are fixed for a specific run, but can be changed from one run to another.		×*
Is the vertical spatial resolution fixed?		×*
Is it operational for forecast at some Institution/VAAC/VO?	×	

2. Model physics

Please, specify if the model accounts for the following parameters/processes:

	Tick	Comments
Topography	×	Works in sigma/eta/hybrid terrain following vertical coordinate
Horizontal wind advection	×	
Vertical wind advection	×	
Horizontal atmospheric diffusion	×	Lateral mixing is simulated with a first order Langevin equation to account for the effects of unresolved horizontal fluctuations of the mean wind (mesoscale fluctuations or meandering). Ref.: Maryon, 1998, *Atmospheric Environment*, **32** (2), 115–121, doi:10.1016/S1352-2310(97)00325-7.
Vertical atmospheric diffusion	×	Vertical mixing is handled through a random displacement equation (diffusion limit of the first order Langevin equation for stationary, inhomogeneous, Gaussian turbulence, i.e. zeroth order model). Vertical diffusion modelled through a diffusion coefficient according to: • Y. Delage formula for surface layer • J. J. O'Brien profile for above layers Ref.: • Delage, Y., 1997, *Boundary-Layer Meteorology*, **82** (1), 23–48, doi:10.1023/A:1000132524077. • O'Brien, J. J., 1970, *Journal of the Atmospheric Sciences*, **27** (8), 1213–1215, doi:10.1175/1520-0469(1970)027<1213:ANOTVS>2.0.CO;2.
Particle sedimentation	×	Gravitational settling modelled according to Stokes' law through a particle/grain size distribution.
Other dry deposition mechanisms	×	Trajectory reflection probability formalism near the surface (modelled in term of a deposition velocity and an absorption probability). Ref.: Wilson *et al.*, 1989, *Agricultural Forest and Meteorology*, **47** (2–4), 139–

		154, doi:10.1016/0168-1923(89)90092-0.
Wet deposition (wet removal)	×	Wet scavenging modelled when a particle is presumed to be in a cloud.
Dry particle aggregation		
Wet particle aggregation		
Particle shape		
Dispersal of different gas species		No, except for inert tracer mode.
Chemical processes		
Others	×	Radioactive decay, survival rate of Footh-and-Mouth Disease virus, Avian Influenza

3. Particle granulometry

	YES	NO	Comments
Is the number of classes (bins) fixed?		×	The particle (grain) size distribution can be defined by the user.
Is the granulometric distribution arbitrary?		×	
Is there an upper/lower limit on the particle size?		×	However, the density of a particle is fixed for all size classes.

4. Meteorological data

	Tick	Comments
On-line coupling		
Off-line coupling	×	Linked to Environment Canada's NWP GEM Global/Regional Model.

	YES	NO
Is the model linked to a particular NWP model?	×	
Is there some pre-process interface for NWP data interpolation?	×	

If the model can assimilate meteorological data from different NWP models or meteorological datasets, please specify which ones:
Yes. ECMWF, NCEP/NCAR re-analysis

Please specify the meteorological variables required:
Geopotential height, surface pressure, temperature, 3D wind speeds/directions (horizontal and vertical motion), humidity (specific humidity or relative humidity or dew point spread).

5. Eruptive column (source term)

Please specify which of the following options are possible for describing the mass (concentration) distribution along the eruptive column

	Tick	Comments
Point source	×	
Uniform (linear) vertical distribution	×	
Umbrella-type (top-hat)	×	
Poisson distribution	×	
Log-normal (Suzuki) distribution (e.g. Suzuki 1983; Armienti et al. 1988)		Could be added.
Buoyant plume theory		
Others	×	The eruptive vertical column distribution can be defined by the user.

	YES	NO
Can transient columns be described? * We can modulate the release as a function of time and height, including lulls.	×*	
Can data (e.g. from satellite retrievals) be assimilated as an "initial" source term condition? * Indirectly. The data are used by the modeller to define the input parameters. However, they are not inputted directly in the model parameters (i.e. without human intervention).	×*	

6. Model outputs

Please specify if the model outputs the following variables (or, in case it just outputs a primary variable – mass, concentration, puff or particle location, etc – if it exists a postprocess utility to compute them):

	Tick	Comments
Tephra deposit load	×	Mass per unit surface.
Tephra deposit thickness		
Airborne concentration	×	
Airborne concentration profiles (e.g. at a given height or flight level)	×	Given height and in layers.
Vertical concentration profiles	×	
Aerosol optical depth		
Aerosol (gas) concentration	×	Indirectly, in tracer mode.
Cloud mass		Not done in our operational response because it is not required, but could easily be done.
Cloud area/volume		Not done (highly dependant on how one defines "the cloud").
Concentration at ground level	×	
Others	×	4D geospatial coordinates of Lagrangian particles, age of particles, etc.

Please specify the model output format

	Tick	Comments
ASCII		
Binary (exclusive of the model)	×	Exclusive to EC/CMC
netCDF		
Grib1	×	Output can easily be converted to binary GRIB format
Grib2		
Graphic format (e.g, eps, gif)	×	
Others	×	PS, JPEG, PNG, TIF, SHP (shapefile), etc.

7. Computational characteristics

Programming language	Fortran 90	
Operating system	Linux/AIX	
	YES	NO
Does a parallel version of the code exist?	×	
Is it an open source/public code?		×
External library packages:		

8. Others

References

Main references:

D'Amours, R., Malo, A., Servranckx, R., Bensimon, D., Trudel, S., Gauthier, J.-P., 2010, "Application of the atmospheric Lagrangian particle dispersion model MLDP0 to the 2008 eruptions of Okmok and Kasatochi volcanoes", *Journal of Geophysical Research*, in press (accepted 2 June 2010), doi:10.1029/2009JD013602 (note: DOI link not yet accessible).

Servranckx, R., Malo, A., July 2010, "Technical Document no. 778, Annex 4: RSMC Montréal Users' Interpretation Guidelines Atmospheric Transport Model Outputs, Version 10", Document distributed to World Meteorological Organization (WMO), Canadian Meteorological Centre, RSMC Montréal, Environmental Emergency Response Section, Dorval, QC, Canada, 17 pp.

D'Amours, R., Malo, A., 2004, "A Zeroth Order Lagrangian Particle Dispersion Model MLDP0", *Internal Publication*, Canadian Meteorological Centre, Environmental Emergency Response Section, Dorval, QC, Canada, 19 pp.

Other references:

Becker A., Wotawa, G., De Geer, L.-E., Seibert, P., Draxler, R. R., Sloan, C., D'Amours, R., Hort, M., Glaab, H., Heinrich, P., Grillon, Y., Shershakov, V., Katayama, K., Zhang, Y., Stewart, P., Hirtl, M., Jean, M., Chen, P., 2007, "Global backtracking of anthropogenic radionuclides by means of a receptor oriented ensemble dispersion modelling system in support of Nuclear-Test-Ban Treaty verification", *Atmospheric Environment*, **41** (21), 4520–4534, doi:10.1016/j.atmosenv.2006.12.048.

Durant, A. J., Rose, W. I., 2009, "Sedimentological constraints on hydrometeor-enhanced particle deposition: 1992 Eruptions of Crater Peak, Alaska", *Journal of Volcanology and Geothermal Research*, **186** (1-2), 40–59, doi:10.1016/j.jvolgeores.2009.02.004.

Potempski, S., Galmarini, S., Addis, R., Astrup, P., Bader, S., Bellasio, R., Bianconi, R., Bonnardot, F., Buckley, R., D'Amours, R., van Dijk, A., Geertsema, G., Jones, A., Kaufmann, P., Pechinger, U., Persson, C., Polreich, E., Prodanova, M., Robertson, L., Sørensen, J., Syrakov, D., 2008, "Multi-model ensemble analysis of the ETEX-2 experiment", *Atmospheric Environment*, **42** (31), 7250–7265, doi:10.1016/j.atmosenv.2008.07.027.

Stocki, T. J., Armand, P., Heinrich, P., Ungar, R. K., D'Amours, R., Korpach, E. P., Bellivier, A., Taffary, T., Malo, A., Bean, M., Hoffman, I., Jean, M., 2008, "Measurement and modelling of radioxenon plumes in the Ottawa Valley", *Journal of Environmental Radioactivity*, **99** (11), 1775–1788, doi:10.1016/j.jenvrad.2008.07.009.

Other comments

The model MLDP0 is tightly coupled with the 4D visualization & analysis software toolkit SPI developed for the needs of Environmental Emergency Response Section (EERS) of the Canadian Meteorological Centre (CMC).

1. Model overview

Model Name	**MOCAGE-accident**	
Approach		Tick
	Eulerian	x
	Lagrangian	
	Hybrid	
Method		Tick
	Analytical (e.g. Gaussian)	
	Semi-analytical	
	Numerical	x
Model coverage		Tick
	Local (order of 100s of km)	
	Regional (order of 1000s of km)	
	Global (globe coverage, periodicity)	x

	YES	NO
Is the horizontal spatial resolution fixed?	x (see comment)	
Is the vertical spatial resolution fixed?	x (see comment)	
Is it operational for forecast at some Institution/VAAC/VO?	x	

<u>Comment</u> : In operations, MOCAGE-accident is currently used with 0.5° resolution and 47 vertical levels (up to 25km of altitude ; Planetary Boundary Layer has ~7 levels, and resolution in the free troposphere ranges from 500m to 800m approximately at the tropopause). In “study mode”, finer resolution can be used over limited area domains, in particular on the horizontal (e.g. 0.1°). Vertical resolution can be increased also, but this requires specific validation.

2. Model physics

Please, specify if the model accounts for the following parameters/processes:

	Tick	Comments
Topography	x	From the ARPEGE operational Numerical Weather Prediction Model of Météo-France, averaged at 0.5° resolution.
Horizontal wind advection	x	Semi-lagrangian advection scheme (Williamson and Rasch, 1989) using a cubic polynomial interpolation in all three directions.
Vertical wind advection	x	See above.
Horizontal atmospheric diffusion		Neglected. Diffusion of numerical origin appears to be sufficient, with particularly good results at 0.5° (Pisso et al., 2009)
Vertical atmospheric diffusion	x	K-scheme from (Louis, 1979); the

		vertical diffusion coefficient K depends on height, wind shear and atmospheric stability.
Particle sedimentation	x	Settling velocity depends on the size and density of particles.
Other dry deposition mechanisms	x	Simple treatment of dry deposition, using fixed deposition velocities. The “study mode” version offers a more detailed aerosol dry deposition scheme (Nho et al., 2004).
Wet deposition (wet removal)	x	Use of a detailed scheme which takes into account the convective part following (Mari et al., 2000) and the stratiform part following (Liu et al., 2001).
Dry particle aggregation		No representation yet.
Wet particle aggregation		No representation yet.
Particle shape		No representation yet.
Dispersal of different gas species	x	Any gas that can be considered as a tracer can be treated, if basic characteristics (such as molar weight and Henry’s Law constants) are defined by the user.
Chemical processes		Chemical processes are not implemented in MOCAGE-accident, but are part of MOCAGE. MOCAGE is the 3D CTM of Météo-France used both in operations and research, for applications from air quality forecasting to the study of interactions between climate and chemistry. MOCAGE-accident is a sub- version of MOCAGE, dedicated to accidental release without chemistry (only possibly radioactive decay). Point source release of reactive gases is a possible option with MOCAGE, but not in an operational context.
Others	x	Convection is accounted for: transport by convection is based on the mass flux scheme of (Bechtold et al., 2001), with embedded representation of scavenging (Mari et al., 2000).

3. Particle granulometry

	YES	NO	Comments
Is the number of classes (bins) fixed?	x		In the current operational version for VAAC, only one size of particles is considered (10µm). In "study mode", several classes can be used to represent the size spectrum, with a full flexibility on the number of classes.
Is the granulometric distribution arbitrary?	x		It is planned to implement shortly an arbitrary distribution; number of classes used is not definitely fixed yet and should be of the order of 5 to 8 classes, which is fully tractable within the strong time constraints.
Is there an upper/lower limit on the particle size?	x		In the future version, there will be an upper limit (e.g. 65 or 100µm) and a lower limit (e.g. 0.2µm).

4. Meteorological data

	Tick	Comments
On-line coupling		
Off-line coupling	x	

	YES	NO
Is the model linked to a particular NWP model?		x
Is there some pre-process interface for NWP data interpolation?	x	

If the model can assimilate meteorological data from different NWP models or meteorological datasets, please specify which ones:
In the operational version for VAAC Toulouse, choice is given to the forecaster on duty between operational global NWP models from Météo-France (ARPEGE) and ECMWF (IFS). In "study mode", MOCAGE-accident can be fed (in principle, but requiring validation) with any meteorological datasets if available in grid points, after pre-processing (formatting for MOCAGE read-in routine, but also computation of vertical velocity, see below). MOCAGE has been already successfully run with a range of met. forcings : HIRLAM, ARPEGE-Climate, ECHAM, AROME.

Please specify the meteorological variables required:
Hydrostatic winds (vertical velocity is re-computed systematically to ensure rigorous non-divergence on the model grid), temperature, pressure, humidity and rainfall at the surface.

5. Eruptive column (source term)

Please specify which of the following options are possible for describing the mass (concentration) distribution along the eruptive column

	Tick	Comments
Point source	x	
Uniform (linear) vertical distribution	x	Base of the column is the volcano altitude. Top of the column is prescribed by the operator.
Umbrella-type (top-hat)		
Poisson distribution		
Log-normal (Suzuki) distribution (e.g. Suzuki 1983; Armienti et al. 1988)		
Buoyant plume theory		
Others		

<u>Comment</u> : Work is planned to provide more options for the forecaster on duty in the operational configuration of MOCAGE-accident.

	YES	NO
Can transient columns be described?		x (see comment)
Can data (e.g. from satellite retrievals) be assimilated as an "initial" source term condition?		X

<u>Comment</u> : In operations currently, the source term is prescribed simply; characteristics -base and top of the column, as well as emission rate and particle size and density- remain constant over the whole duration of an individual forecast (persistency is assumed, with no hypothesis on future source term evolution) , but can indeed change from one forecast to the next one. In study mode, characteristics of the release can change arbitrarily in time.

6. Model outputs

Please specify if the model outputs the following variables (or, in case it just outputs a primary variable – mass, concentration, puff or particle location, etc – if it exists a postprocess utility to compute them):

	Tick	Comments
Tephra deposit load	x	
Tephra deposit thickness		
Airborne concentration	x	
Airborne concentration profiles (e.g. at a given height or flight level)	x	In study mode only
Vertical concentration profiles	x	In study mode only
Aerosol optical depth	x	In study mode only
Aerosol (gas) concentration		Airborne concentrations?

Cloud mass	x	In study mode only
Cloud area/volume		
Concentration at ground level	x	
Others		

Please specify the model output format

	Tick	Comments
ASCII		
Binary (exclusive of the model)	x	
netCDF	x	In study mode only
Grib1	x	
Grib2		
Graphic format (e.g, eps, gif)	x	png
Others		

7. Computational characteristics

Programming language	Fortran 77/90	
Operating system	UNIX	
	YES	NO
Does a parallel version of the code exist?	x	
Is it an open source/public code?		x
External library packages:		
libemos		

8. Others

References
Other comments

1. Model overview

Model Name	**NAME (Numerical Atmospheric dispersion Modelling Environment)**		
Approach			Tick
	Eulerian		
	Lagrangian		✓ [1]
	Hybrid		
Method			Tick
	Analytical (e.g. Gaussian)		
	Semi-analytical		
	Numerical		✓
Model coverage			Tick
	Local (order of 100s of km)		✓
	Regional (order of 1000s of km)		✓
	Global (globe coverage, periodicity)		✓
		YES	NO
Is the horizontal spatial resolution fixed?			✓
Is the vertical spatial resolution fixed?			✓
Is it operational for forecast at some Institution/VAAC/VO?		✓ [2]	

2. Model physics

Please, specify if the model accounts for the following parameters/processes:

	Tick	Comments
Topography	✓	Uses topography from the driving NWP meteorological model
Horizontal wind advection	✓	
Vertical wind advection	✓	
Horizontal atmospheric diffusion	✓ [3]	
Vertical atmospheric diffusion	✓ [3]	
Particle sedimentation	✓	Based on Stokes flow with the Cunningham correction applied for small particle sizes
Other dry deposition mechanisms	✓	a) Land-surface dependent dry deposition scheme (based on surface resistance concept) – not used for volcanic ash applications b) Simple surface resistance scheme
Wet deposition (wet removal)	✓	Rain out (in-cloud removal) and wash out (below-cloud removal by rain impaction).
Dry particle aggregation	✗	
Wet particle aggregation	✗	
Particle shape	✗	
Dispersal of different gas species	✓	Species can have different chemical and radiological properties and

		different deposition characteristics.
Chemical processes	✓	Comprehensive sulphur/nitrogen/hydrocarbon chemistry scheme used for air quality modelling applications. Sulphate chemistry has also been used for volcanic ash research studies.
Others		Radiological decay (half-life decay and decay chains), cloud gamma and dose assessments; decay of biological and vector species; deep convective mixing.

3. Particle granulometry

	YES	NO	Comments
Is the number of classes (bins) fixed?		✓	User-specified
Is the granulometric distribution arbitrary?	✓		User-specified particle size distribution (cumulative fraction)
Is there an upper/lower limit on the particle size?		✓	Normally applied for particle size range 0.1 µm – 100.0 µm for volcanic ash applications

4. Meteorological data

	Tick	Comments
On-line coupling		
Off-line coupling	✓	NAME reads 3-d fields output from an NWP model at a specified frequency (operational data is currently 3-hourly for global NWP forecasts; hourly for higher resolution NWP models). NAME supports the nesting of different met data sets within the same run (e.g. high resolution forecast data nested within a global forecast).

	YES	NO
Is the model linked to a particular NWP model?		✓
Is there some pre-process interface for NWP data interpolation?		✓

If the model can assimilate meteorological data from different NWP models or meteorological datasets, please specify which ones:
a) UK Met Office Unified Model (MetUM) a. global (~25km) b. regional (North Atlantic/Europe at ~12km) c. high resolution (UK at 4 km and 1.5 km) b) ECMWF IFS (real-time forecasts)

  a. operational deterministic
  b. Ensemble Prediction System

c) ECMWF ERA (reanalysis products)
  a. ERA-40
  b. ERA-Interim

d) Single-site met observations typical of a surface weather observation station (for short-range applications)

e) Rainfall radar data

Please specify the meteorological variables required:
The full set of meteorological variables is listed here, but NAME can be run on a ºsubset of these if not all the variables are available. **Model-level fields (3-dimensional):** u,v,w wind components temperature specific humidity dynamic cloud water/ice pressure **Single-level or surface fields (2-dimensional):** u,v surface stress components surface sensible heat flux surface pressure/mean sea level pressure near-surface temperature (e.g. at 2 metres) convective cloud amount/base/top dynamic low/medium/high cloud amounts dynamic/convective rain rates dynamic/convective snow rates roughness length boundary layer depth soil moisture* canopy height* canopy water* stomatal conductance* *optional (not used for volcanic ash modelling)

5. Eruptive column (source term)

Please specify which of the following options are possible for describing the mass (concentration) distribution along the eruptive column

	Tick	Comments
Point source	✓	
Uniform (linear) vertical distribution	✓ [4]	
Umbrella-type (top-hat)	✓	Unsure what is meant by ‘umbrella-type’ here? But NAME

		can model most types of source configurations as composite sources (based on point, line, area and volume components).
Poisson distribution		
Log-normal (Suzuki) distribution (e.g. Suzuki 1983; Armienti et al. 1988)		
Buoyant plume theory	✓	NAME has a plume-rise scheme for buoyancy and momentum driven releases developed for modelling industrial plumes. The scheme solves an integral model for the governing conservation equations of mass, momentum and heat. It is an advancement on the Briggs formulae. The NAME plume rise code is not used for volcanic ash applications (the effective eruption height is always specified directly).
Others		

	YES	NO
Can transient columns be described?	✓	
Can data (e.g. from satellite retrievals) be assimilated as an "initial" source term condition?		✓

6. Model outputs

Please specify if the model outputs the following variables (or, in case it just outputs a primary variable – mass, concentration, puff or particle location, etc – if it exists a postprocess utility to compute them):

	Tick	Comments
Tephra deposit load	✓	NAME was not specifically designed to compute tephra deposits (esp. short-range fallout of very large particles). However there is no physical reason why the existing sedimentation scheme should not be valid for this regime. The fact that aggregation is not treated by NAME may be an issue however.
Tephra deposit thickness	✗	
Airborne concentration	✓	
Airborne concentration profiles (e.g. at a given height or flight level)	✓	
Vertical concentration profiles	✓	
Aerosol optical depth	✓	(as a post-processed quantity)
Aerosol (gas) concentration	✓	

Cloud mass	✓	
Cloud area/volume	✓	In principle these quantities could be computed in a post-processing step, although these variables are not ordinarily calculated.
Concentration at ground level	✓	
Others		A wide range of NAME outputs are possible, including individual particle trajectories, particle travel times, meteorological variables, etc. Statistical processing of output fields (calculation of means, percentiles, etc.) is also available directly in the model.

Please specify the model output format

	Tick	Comments
ASCII	✓	Output files conform to a generic plain text format, but the structure of specific output files is highly configurable through a range of model options (e.g. for fields output, time series at a location, etc).
Binary (exclusive of the model)		
netCDF	✓[5]	
Grib1	✓[5]	
Grib2	✓[5]	
Graphic format (e.g, eps, gif)	✓	IDL used to create output graphics in .ps, .gif, and .png formats
Others		G.I.S. products created via downstream systems (ArcView)

7. Computational characteristics

Programming language	Fortran 95 (using IDL for graphics)		
Operating system	Linux, Windows [6]		
		YES	NO
Does a parallel version of the code exist?		✓[7]	
Is it an open source/public code?			✓
External library packages:			
ECMWF 'GRIBEX' package required for running on ECMWF GRIB1 met files.			

8. Others

References
Jones, A.R., Thomson, D.J., Hort, M. and Devenish, B., "The U.K. Met Office's next-generation atmospheric dispersion model, NAME III", in Borrego, C. and Norman, A.-L. (Eds) Air Pollution

Modeling and its Application XVII (Proceedings of the 27th NATO/CCMS International Technical Meeting on Air Pollution Modelling and its Application), Springer, pp. 580-589, 2007.

Witham, C.S., Hort, M.C., Potts, R., Servranckx, R., Husson, P. and Bonnardot, F., "Comparison of VAAC atmospheric dispersion models using the 1 November 2004 Grimsvötn eruption", Meteorological Applications 14, 27-38, 2007.

Other comments
Notes: [1] NAME also uses non-Lagrangian techniques for modelling certain processes (e.g. chemistry). Chemistry is not used in volcanic ash applications, although has been used for modelling volcanic SO_2 plumes. [2] Operational atmospheric dispersion model at the UK Met Office (WMO RSMC for radiological emergency response; VAAC for Volcanic Ash; UK civil emergency response). [3] NAME uses random-walk techniques of varying levels of sophistication to treat plume diffusion. Within the boundary layer, the default (fast) scheme assumes vertically homogeneous turbulence with a diffusive scheme damped for the slower plume growth rate at small travel times. 'Turbulence' and 'meander' scales are treated independently. A more comprehensive (but slower) treatment is provided by 'near-source' schemes that includes inhomogeneous turbulence profiles and the velocity memory of particles. A constant-magnitude 'free tropospheric' turbulence is applied above the boundary layer. For volcanic ash applications only the most simple turbulence scheme is used. [4] NAME supports point, line, area and volume sources using either a uniform distribution or Gaussian distribution. For volcanic ash applications, a uniform vertical distribution is adopted: column_min $\leq$ z $\leq$ column_max. [5] Currently available via downstream post-processing. However adding functionality to generate output directly in these formats is planned for late 2010. [6] Primary operating systems used are Linux and Windows, but NAME has also been compiled for SUN Solaris and Mac systems. [7] Parallelisation uses OpenMP architecture to run on shared-memory systems.

1. Model overview

Model Name	**Puff VATD Model**	
Approach		Tick
	Eulerian	
	Lagrangian	√
	Hybrid	
Method		Tick
	Analytical (e.g. Gaussian)	
	Semi-analytical	
	Numerical	√
Model coverage		Tick
	Local (order of 100s of km)	√
	Regional (order of 1000s of km)	√
	Global (globe coverage, periodicity)	√

	YES	NO
Is the horizontal spatial resolution fixed?		√
Is the vertical spatial resolution fixed?		√
Is it operational for forecast at some Institution/VAAC/VO?	√	

2. Model physics

	Tick	Comments
Topography	√	Using gtopo30 DEM
Horizontal wind advection	√	
Vertical wind advection	√	
Horizontal atmospheric diffusion	√	Defined value or 'turbulent' from wind field
Vertical atmospheric diffusion	√	
Particle sedimentation		
Other dry deposition mechanisms	√	Settling can be defined as stokes, Reynolds or constant
Wet deposition (wet removal)		
Dry particle aggregation		
Wet particle aggregation		
Particle shape	√	Considered to be spherical
Dispersal of different gas species		
Chemical processes		
Others		Puff is a simple advection/dispersion model

3. Particle granulometry

	YES	NO	Comments
Is the number of classes (bins) fixed?		√	Defined by a mean size and s.d or using phi size bins.
Is the granulometric distribution arbitrary?		√	
Is there an upper/lower limit on the particle size?		√	

4. Meteorological data

	Tick	Comments
On-line coupling		
Off-line coupling	√	Numerical Weather Prediction wind data is used to drive the Puff model ash dispersion and transport

	YES	NO
Is the model linked to a particular NWP model?		√
Is there some pre-process interface for NWP data interpolation?		√

If the model can assimilate meteorological data from different NWP models or meteorological datasets, please specify which ones:
GFS, NAM 216 ,NOGAPS, NCEP Reanalysis, WRF Can use any wind field model as long as 3D and Puff source file (puffrc) has defined model and the parameters representing U, V, T and geo_potential_height

Please specify the meteorological variables required:
U, V, T, Geo Pot Height

5. Eruptive column (source term)

	Tick	Comments
Point source	√	Can specify any location globally
Uniform (linear) vertical distribution	√	
Umbrella-type (top-hat)	√	Defined by thickness of umbrella region, uniform shape below
Poisson distribution	√	
Log-normal (Suzuki) distribution (e.g. Suzuki 1983; Armienti et al. 1988)		
Buoyant plume theory		
Others	√	Define plume height, can vary with time or fixed for eruptive event

	YES	NO
Can transient columns be described?	√ (if one means varying heights with time)	
Can data (e.g. from satellite retrievals) be assimilated as an "initial" source term condition?	√ (can be adapted to)	

6. Model outputs

	Tick	Comments
Tephra deposit load		
Tephra deposit thickness		
Airborne concentration	√	Cam be done with accurate input source information

Airborne concentration profiles (e.g. at a given height or flight level)	√	
Vertical concentration profiles	√	Puff is 3D so requires analysis of model outputs but it is possible
Aerosol optical depth		
Aerosol (gas) concentration		
Cloud mass		
Cloud area/volume	√	
Concentration at ground level	√	With accurate input source terms and scaling can determine load as mg/m^2
Others		

Please specify the model output format

	Tick	Comments
ASCII	√	Requires using netcdf reader and then can output to ascii
Binary (exclusive of the model)		
netCDF	√	Output files for concentrations are '.nc' and for airborne particles are 'cdf'
Grib1		
Grib2		
Graphic format (e.g, eps, gif)	√	Images as png, jpeg, gif. Animations as mpeg and gif.
Others	√	Web based outputs as html, php and also Google Earth KML and KMZ.

7. Computational characteristics

Programming language	C and C++ with additional libraries, with shell and perl scripts for automated forecasts		
Operating system	Unix/Linux		
		YES	NO
Does a parallel version of the code exist?			√
Is it an open source/public code?		√	
External library packages:			
Requires netcdf, udunits library			

8. Others

References
Searcy, C., Dean, K. G., Stringer, W., 1998. PUFF: A volcanic ash tracking and prediction model, *Journal of Volcanology and. Geothermal Research,* **80**, 1-16.   Peterson, R. A., Dean, K. G., 2008. "Forecasting exposure to airborne volcanic ash based on ash dispersion modeling", *J. Volcanology and Geothermal Res.* **170**, 230-246 doi:10.1016/j.jvolgeores.2007.10.003.

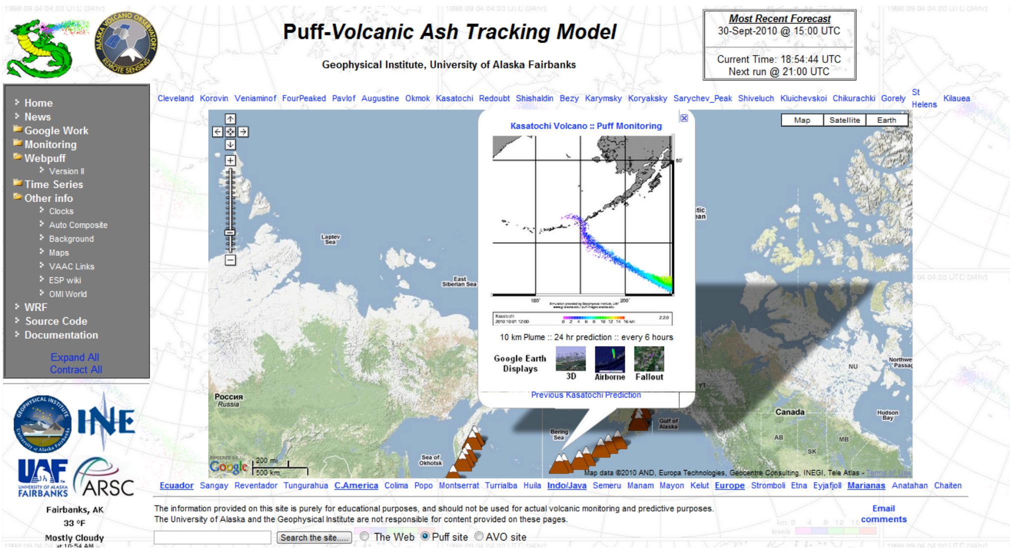
Webley, P.W., 2010. Four Dimensional Volcanic Ash Cloud Predictions in Google Earth, with a special case of an ash-aviation encounter. *Computer and Geosciences Special Issue: Virtual Globes*. doi:10.1016/j.cageo.2010.02.005.

Webley, P. W., Dean, K. G., Dehn, J. Bailey, J. E., Peterson, R., 2010. Volcanic Ash Dispersion Modeling of the 2006 Eruption of Augustine Volcano *USGS Professional Paper: Augustine Volcano 2006 eruption.* **In Press**.

Other comments

The Puff Volcanic Ash Dispersion and Transport model has been developed at the University of Alaska Fairbanks – Geophysical Institute. The model runs quickly and has been used extensively in the Alaska and North Pacific Region by the Alaska Volcano Observatory, U. S. National Weather Service (VAAC, AAWU and CSWU) and AirForce Weather Agency.

The Puff model website, http://puff.images.alaska.edu see Figure 1, provides an online interface to the model. As of October 1, 2010, automated forecasts are provided for 37 volcanoes globally, every 3 – 6 hrs, for initial plume altitudes from 4 – 16 km above sea level. These are 24 hour forecasts, with model outputs every 1 hr. Additionally, model outputs are provided in gif and Google Earth KML/KMZ format to allow automated viewing of forecasts without forecasters having to be sure they are using the most recent model run. Outside Alaska and North Pacific, the model is used routinely by the Darwin VAAC and also OVSICORI in Costa Rica as a tool to provide a validation tool to their own forecasts as with Darwin and as a new and novel visualization and forecasting tool for OVSICORI.



<u>Figure 1</u> Puff Volcanic Ash Transport and Dispersion model website

We provide an interactive page, http://puff.images.alaska.edu/auto_forecasts_new.php see Figure 2, where one can view all the model runs for each volcano and start height. This is useful to be able to choose the volcano and plume initial height. The user can then view the animation of ash cloud movement and a set time period in the forecast.

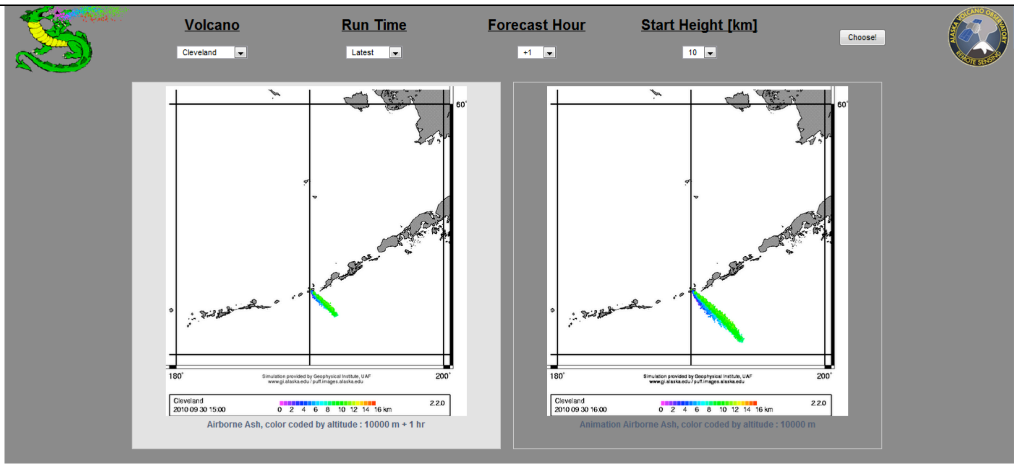


Figure 2 Interface to Puff model forecasts, where user can choose volcano and start height from drop down menus

When a given volcanic event is detected, the Puff model can be run through an interface for the time of the start of the event, http://puff.images.alaska.edu/cgi-bin/login_agu.pl, see Figure 3. The user can define plume height, eruption length, simulation length, output timing, wind field model, number of ash particles and plume shape. The user can return later to view any previous model run, they can edit the plotted ash cloud maps and generate a Google Earth KML/KMZ file of their model run simulation.

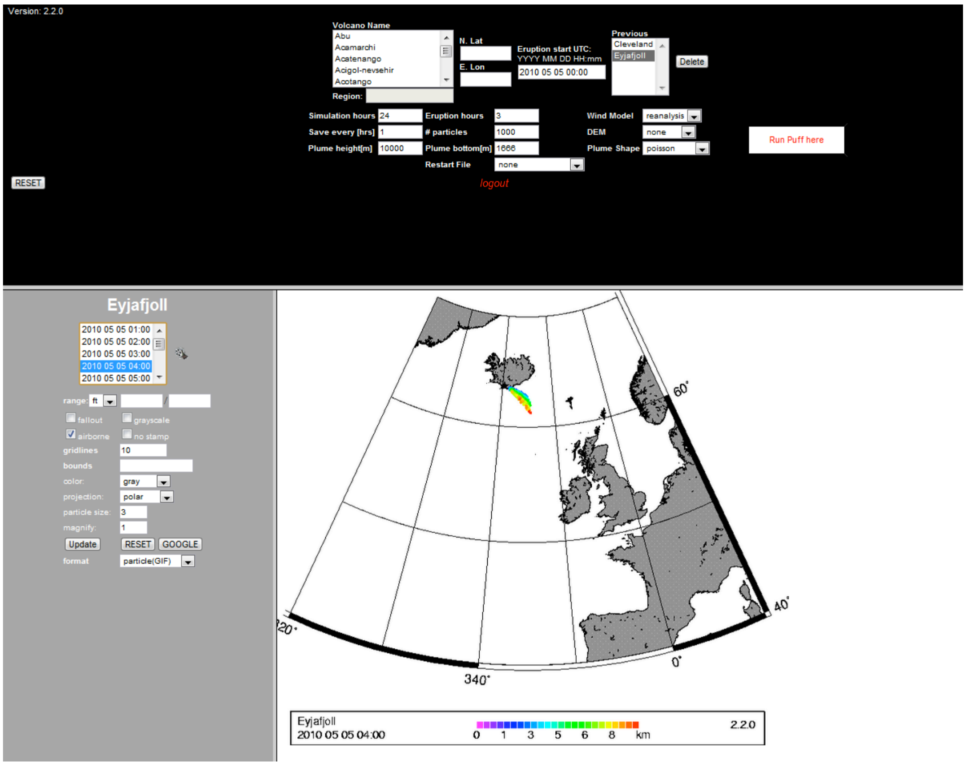


Figure 3 Webpuff interface to allow users to run their own Puff model simulations

Recently, the Puff model has been developed to allow an ash exposure tool to be adapted. This allows the users to provide an aircraft route and from airborne concentrations determine the exposure over time of the aircraft, see Peterson and Dean (2008).

Finally, the Puff VATD model has the capabilities to forecast multiple eruptive events. If a volcano, such as Augustine did in 2006 and has multiple events over a short period of time, then they will be multiple airborne ash clouds that needed to be forecasted. Puff allows the user to run a 'restart' from a previous model run. This allows multiple ash clouds to be tracked, with 6 being forecasted in the Augustine 2006 eruption, see Webley et al (in press)

1. Model overview

Model Name	TEPHRA2	
Approach		Tick
	Eulerian	X
	Lagrangian	
	Hybrid	
Method		Tick
	Analytical (e.g. Gaussian)	X
	Semi-analytical	
	Numerical	
Model coverage		Tick
	Local (order of 100s of km)	X
	Regional (order of 1000s of km)	
	Global (globe coverage, periodicity)	

	YES	NO
Is the horizontal spatial resolution fixed? ➔ Defined by the calculation grid adopted		X
Is the vertical spatial resolution fixed?		X
Is it operational for forecast at some Institution/VAAC/VO? ➔ INGV Catania	X	

2. Model physics

Please, specify if the model accounts for the following parameters/processes:

	Tick	Comments
Topography	X	
Horizontal wind advection	X	
Vertical wind advection		
Horizontal atmospheric diffusion	X	Accounts for plume diffusion (i.e. plume radius increase with height) and for two diffusion laws: -> linear (Fickian) diffusion for large particles -> power-law diffusion for small particles (Suzuki 1983)
Vertical atmospheric diffusion		
Particle sedimentation	X	
Other dry deposition mechanisms		
Wet deposition (wet removal)		
Dry particle aggregation		
Wet particle aggregation		
Particle shape		
Dispersal of different gas species		
Chemical processes		
Others	X	Variable particle velocity with height and Reynold's number

3. Particle granulometry

	YES	NO	Comments
Is the number of classes (bins) fixed?	X		
Is the granulometric distribution arbitrary?	X		Gaussian
Is there an upper/lower limit on the particle size?		X	

4. Meteorological data

	Tick	Comments
On-line coupling		
Off-line coupling		

	YES	NO
Is the model linked to a particular NWP model?		X
Is there some pre-process interface for NWP data interpolation?		X

If the model can assimilate meteorological data from different NWP models or meteorological datasets, please specify which ones:
NCEP/NCAR, ECMWF Re-analysis

Please specify the meteorological variables required:
Geopotential height, U-wind, V-wind

5. Eruptive column (source term)

Please specify which of the following options are possible for describing the mass (concentration) distribution along the eruptive column

	Tick	Comments
Point source		
Uniform (linear) vertical distribution	X	It is possible to define the plume ratio from which particles start falling.
Umbrella-type (top-hat)	X	
Poisson distribution		
Log-normal (Suzuki) distribution (e.g. Suzuki 1983; Armienti et al. 1988)	X	
Buoyant plume theory		
Others		

	YES	NO
Can transient columns be described?		X
Can data (e.g. from satellite retrievals) be assimilated as an “initial” source term condition?		X

6. Model outputs

Please specify if the model outputs the following variables (or, in case it just outputs a primary variable – mass, concentration, puff or particle location, etc – if it exists a postprocess utility to compute them):

	Tick	Comments
Tephra deposit load	X	
Tephra deposit thickness	X	
Airborne concentration		
Airborne concentration profiles (e.g. at a given height or flight level)		
Vertical concentration profiles		
Aerosol optical depth		
Aerosol (gas) concentration		
Cloud mass		
Cloud area/volume		
Concentration at ground level		
Others	X	Grainsize distribution at each grid point

Please specify the model output format

	Tick	Comments
ASCII	X	
Binary (exclusive of the model)		
netCDF		
Grib1		
Grib2		
Graphic format (e.g, eps, gif)	X	
Others	X	Working on shapefiles (ArcGIS) and Google Earth

7. Computational characteristics

Programming language	C	
Operating system	Unix	
	YES	NO
Does a parallel version of the code exist?	X*	
Is it an open source/public code? ➔ http://www.cas.usf.edu/~cconnor/vg@usf/tephra.html	X	
External library packages:		
* TEPHRA1 (no topography)		

8. Others

References
Bonadonna, C., C. B. Connor, B. F. Houghton, L. Connor, M. Byrne, A. Laing, and T. K. Hincks (2005), Probabilistic modeling of tephra dispersal: Hazard assessment of a multiphase rhyolitic eruption at Tarawera, New Zealand, J. Geophys. Res., 110, B03203, doi:10.1029/2003JB002896. Connor, L. G., and C. B. Connor (2006), Inversion is the key to dispersion: understanding eruption dynamics by inverting tephra fallout, in Statistics in Volcanology, edited by H. Mader, et al., pp. 231-242, Geological Society London http://www.cas.usf.edu/~cconnor/vg@usf/tephra.html
Other comments
A Matlab toolbox is currently being developed to add a graphical interface to the model, as well as to provide tools for (i) collecting, processing and perform statistical analysis on input parameters, (ii) run the model using different deterministic and probabilistic scenarios and (iii) process output data to produce thorough hazard assessments.

1. Model overview

Model Name	**VOL-CALPUFF**	
Approach		Tick
	Eulerian	
	Lagrangian	
	Hybrid	✓
Method		Tick
	Analytical (e.g. Gaussian)	
	Semi-analytical	✓
	Numerical	
Model coverage		Tick
	Local (order of 100s of km)	✓
	Regional (order of 1000s of km)	✓
	Global (globe coverage, periodicity)	

	YES	NO
Is the horizontal spatial resolution fixed?		✓
Is the vertical spatial resolution fixed?		✓
Is it operational for forecast at some Institution/VAAC/VO?		

It is routinely used at INGV – Catania for volcanic ash dispersal forecast at Mt. Etna

2. Model physics

Please, specify if the model accounts for the following parameters/processes:

	Tick	Comments
Topography	✓	
Horizontal wind advection	✓	
Vertical wind advection	✓	
Horizontal atmospheric diffusion	✓	
Vertical atmospheric diffusion	✓	
Particle sedimentation	✓	
Other dry deposition mechanisms		
Wet deposition (wet removal)	✓	Not yet tested for volcanic ash, but already implemented in original CALPUFF code
Dry particle aggregation		
Wet particle aggregation		
Particle shape	✓	
Dispersal of different gas species	✓	Not yet tested for volcanic gases, but already implemented in original CALPUFF code
Chemical processes	✓	As above
Others		

3. Particle granulometry

	YES	NO	Comments
Is the number of classes (bins) fixed?		✔	
Is the granulometric distribution arbitrary?	✔		
Is there an upper/lower limit on the particle size?		✔	

4. Meteorological data

	Tick	Comments
On-line coupling		
Off-line coupling	✔	

	YES	NO
Is the model linked to a particular NWP model?		✔
Is there some pre-process interface for NWP data interpolation?	✔	

If the model can assimilate meteorological data from different NWP models or meteorological datasets, please specify which ones:
ECMWF Re-analysis, GFS (0.5° and 1°), COSMO/Lami, NCEP/NCAR Re-analysis, NAM, NCEP/NARR archive

Please specify the meteorological variables required:
2D: Land use, sea level pressure, precipitation accumulation (for wet deposition) 3D: Wind speed, wind direction, temperature, humidity, vertical velocity (Pa/s)

5. Eruptive column (source term)

Please specify which of the following options are possible for describing the mass (concentration) distribution along the eruptive column

	Tick	Comments
Point source	✔	
Uniform (linear) vertical distribution		Not yet implemented but feasible if required
Umbrella-type (top-hat)		Not yet implemented but feasible if required
Poisson distribution		Not yet implemented but feasible if required
Log-normal (Suzuki) distribution (e.g. Suzuki 1983; Armienti et al. 1988)		Not yet implemented but feasible if required
Buoyant plume theory	✔	

Others		

	YES	NO
Can transient columns be described?	✔	
Can data (e.g. from satellite retrievals) be assimilated as an "initial" source term condition? It is not routinely done, but it is possible to invert the plume theory model in order to define the volcanological input data at the vent able to produce "observed" column heights taking into account the current meteorological condition.		

6. Model outputs

Please specify if the model outputs the following variables (or, in case it just outputs a primary variable – mass, concentration, puff or particle location, etc – if it exists a postprocess utility to compute them):

	Tick	Comments
Tephra deposit load	✔	This is the standard output
Tephra deposit thickness	✔	It is not the standard output, but could be computed with a simple post-processing
Airborne concentration	✔	
Airborne concentration profiles (e.g. at a given height or flight level)	✔	
Vertical concentration profiles	✔	
Aerosol optical depth		
Aerosol (gas) concentration		
Cloud mass	✔	The same as for Tdt
Cloud area/volume	✔	The same as for Tdt
Concentration at ground level	✔	
Others	✔	PMx concentration at surface

Please specify the model output format

	Tick	Comments
ASCII	✔	In order to be read with NCL libraries
Binary (exclusive of the model)		
netCDF		
Grib1		
Grib2		
Graphic format (e.g, eps, gif)	✔	png
Others	✔	VTK file format (to be read by Paraview)

7. Computational characteristics

Programming language	Fortran 77/90		
Operating system	UNIX/LINUX		
		YES	NO
Does a parallel version of the code exist?			✔
Is it an open source/public code?			✔
External library packages:			

8. Others

References

Barsotti, S., D. Andronico, A. Neri, P. Del Carlo, P.J. Baxter, W.P. Aspinall, T. Hincks (2010), Quantitative assessment of volcanic ash hazards for health and infrastructure at Mt. Etna (Italy) by numerical simulation, *Journal of Volcanology and Geothermal Research*, Volume 192, Issues 1-2, 20 April 2010, Pages 85-96.

Barsotti, S., L.G. Mastin, L. Nannipieri, A. Neri, J.R. Schaefer, K.L. Wallace, D.J. Schneider, (2009), Ash dispersal forecasts and event reconstruction of the Redoubt Volcano's 2009 explosive activity using the VOL-CALPUFF model, *AGU Fall meeting 2009*, San Francisco.

Barsotti, S., and A. Neri (2008), The VOL-CALPUFF model for atmospheric ash dispersal: 2. Application to the weak Mount Etna plume of July 2001, *Journal of Geophysical Research,* 113, B03209, doi:10.1029/2006JB004624.

Barsotti, S., A. Neri, and J. S. Scire (2008a), The VOL-CALPUFF model for atmospheric ash dispersal: 1. Approach and physical formulation, *Journal of Geophysical Research*, 113, B03208, doi:10.1029/2006JB004623.

Barsotti S., L. Nannipieri and A. Neri (2008b), MAFALDA: An early warning modeling tool to forecast volcanic ash dispersal and deposition, *G-cube*, doi: 10.1029/2008GC002133.

Other comments

I filled the present module keeping in mind the current version of the VOL-CALPUFF code. It is still true that with more or less simple pre and post-processing it would be possible to modify the type of output information, output format, or input source description.