Tephra fallout hazard maps with uncertainty quantification for Cotopaxi and Guagua Pichincha volcanoes

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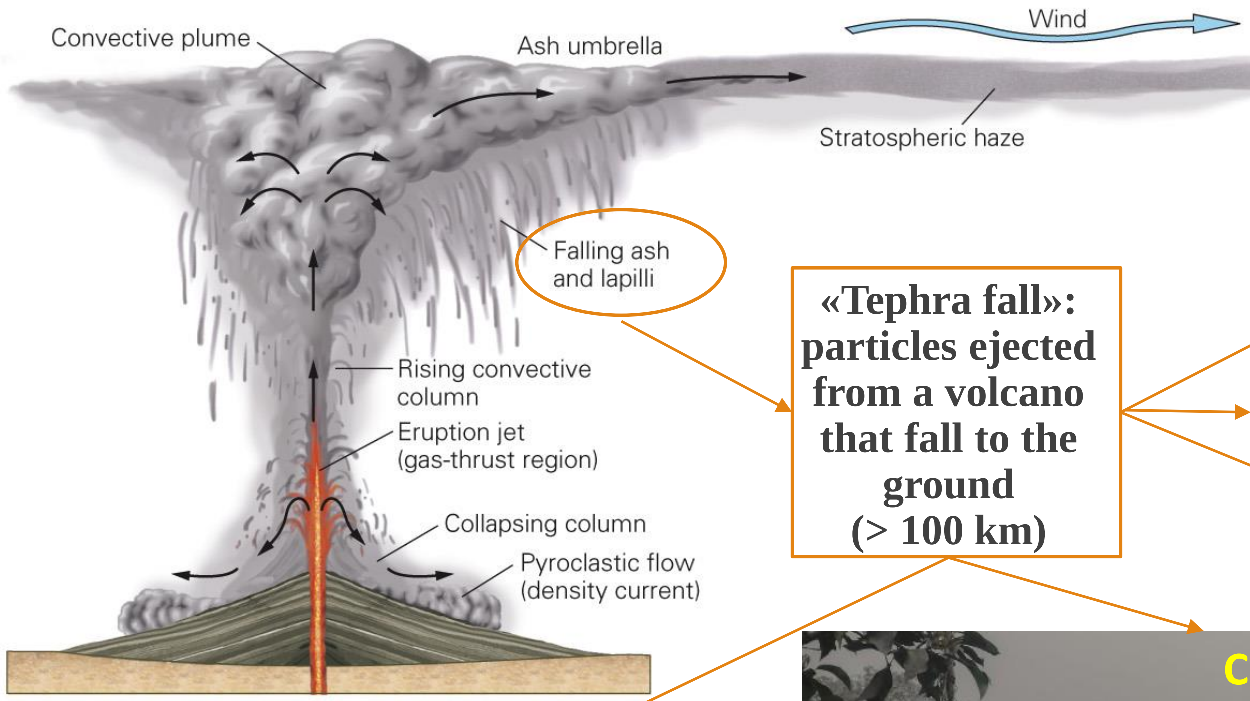
Julia Eychenne, Silvana Hidalgo, Augusto Neri, Raffaello Cioni, Marco Pistolesi, Federica Pardini, Willy Aspinall, Elizabeth Gaunt, Silvia Vallejo, Marjorie Encalada, Hugo Yepes, Antonio Proaňo, Mia Pique, Jean-Luc Le Pennec

Volcanic eruptions

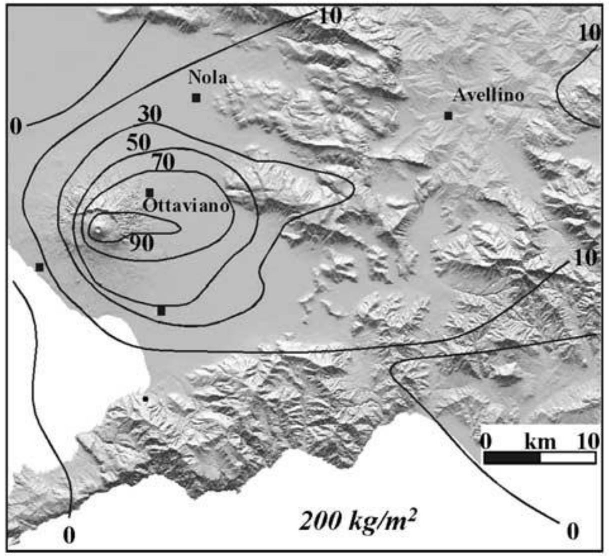


«Tephra fall»: particles ejected from a volcano that fall to the ground (> 100 km)

Volcanic hazard assessemnt: hazard maps

Maps related to mass loading (kg/m^2 ou g/cm^2) or thickness (cm or mm)

Field data



Cioni et al., 2003

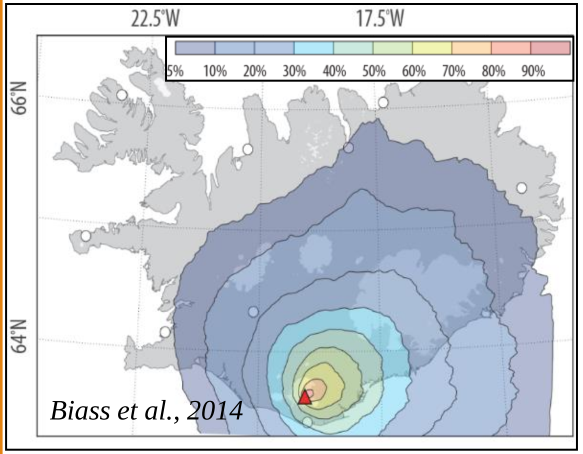
Deterministic

- One scenario
- Defined parameters

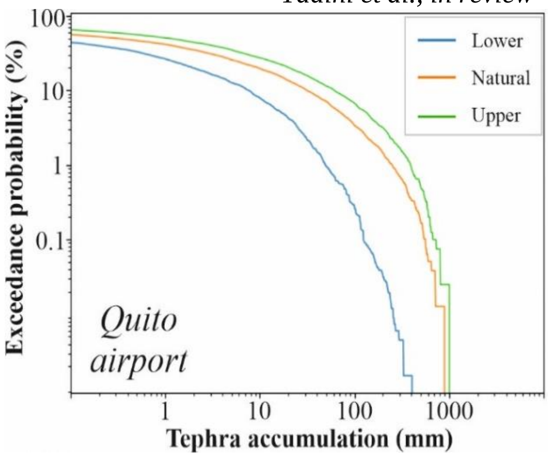
Numerical models

Probabilistic or Semi-probabilistic

- One or multiple scenarii
- Set of parameters
- Monte Carlo sampling



Tadini et al., in review



Hazard maps

- given threshold
- given probability

Hazard curves

- site(s) of interest
- Exceedance probability

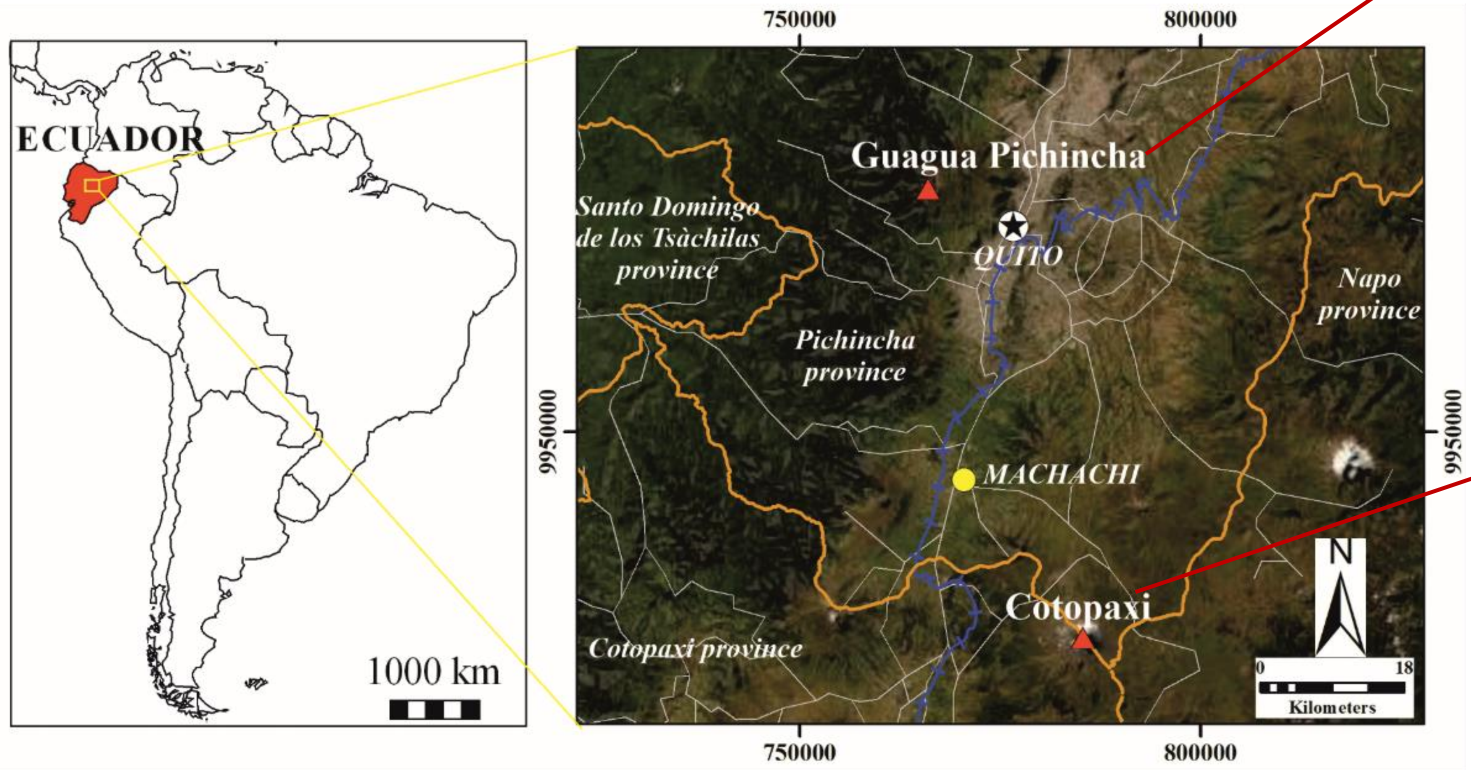
Sources of uncertainty

- Uncertainty in input paramters
- Uncertainty of the numerical model
- Uncertainty on different eruption type occurrence

Volcanoes in Ecuador

- 21 active volcanoes in Ecuador (holocene activity)
- Quito threatened by several active volcanoes
- Several studies linked to tephra fallout hazard map production but :
  - a probabilistic approach has not been used systematically
  - uncertainty quantification has not always been applied

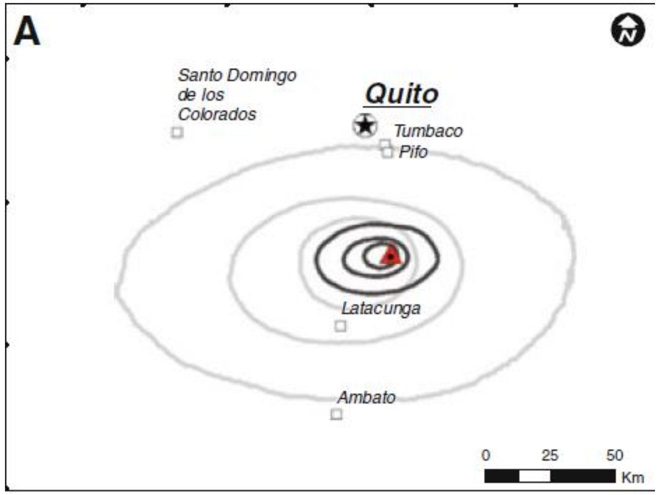
GUAGUA PICHINCHA



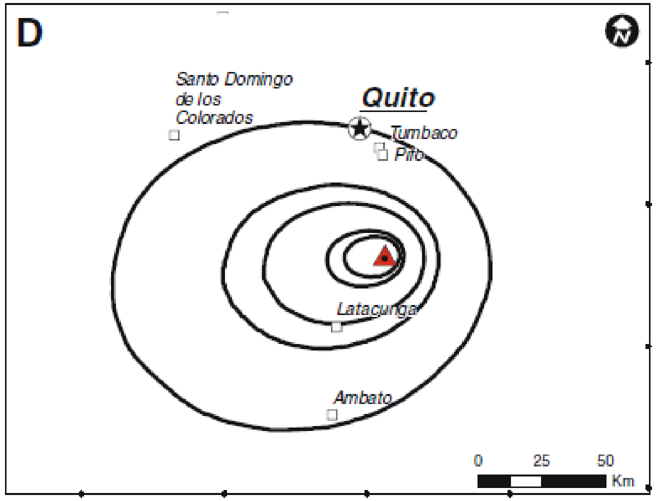
COTOPAXI

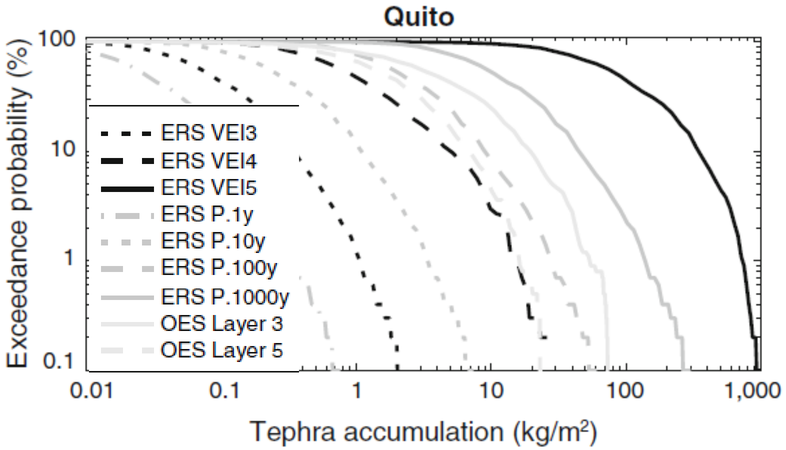
Cotopaxi: tephra fallout hazard assessment

Probability contours for given threshold values of mass loading



Different values of mass load for a given probability of occurrence (50%)





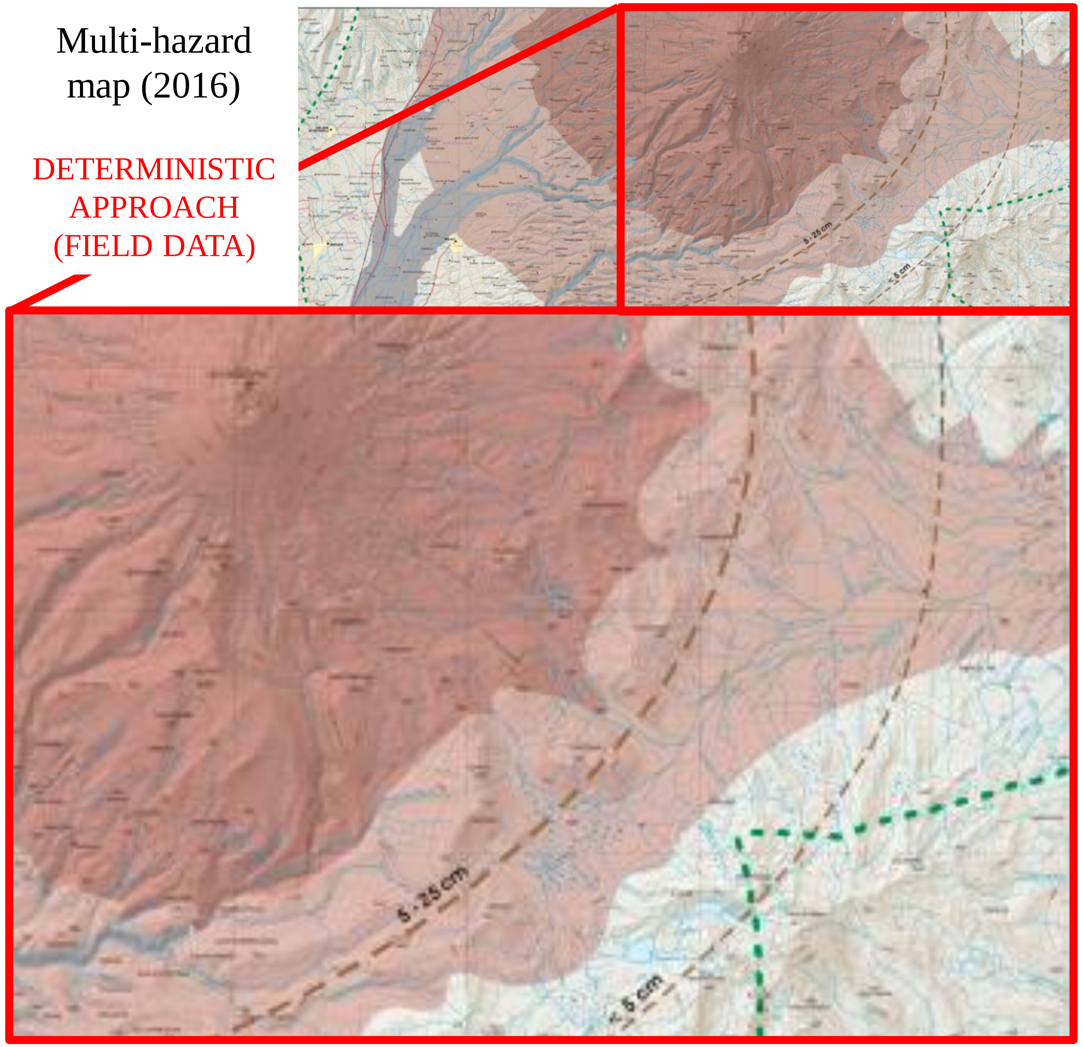
Biass and Bonadonna, 2013

Hazard curves for specific sites

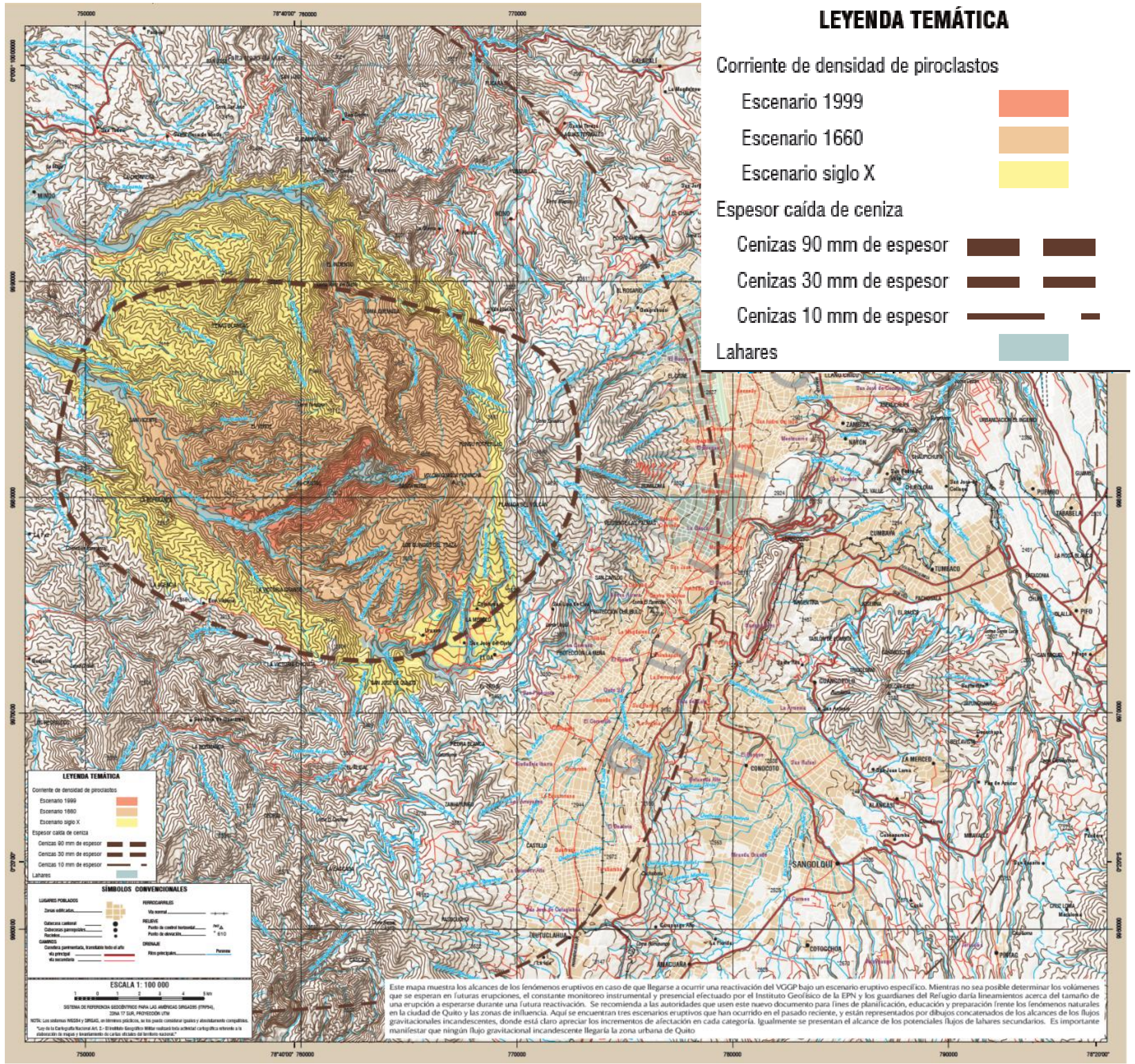
SEMI-PROBABILISTIC and PROBABILISTIC APPROACH (TEPHRA 2)

Multi-hazard map (2016)

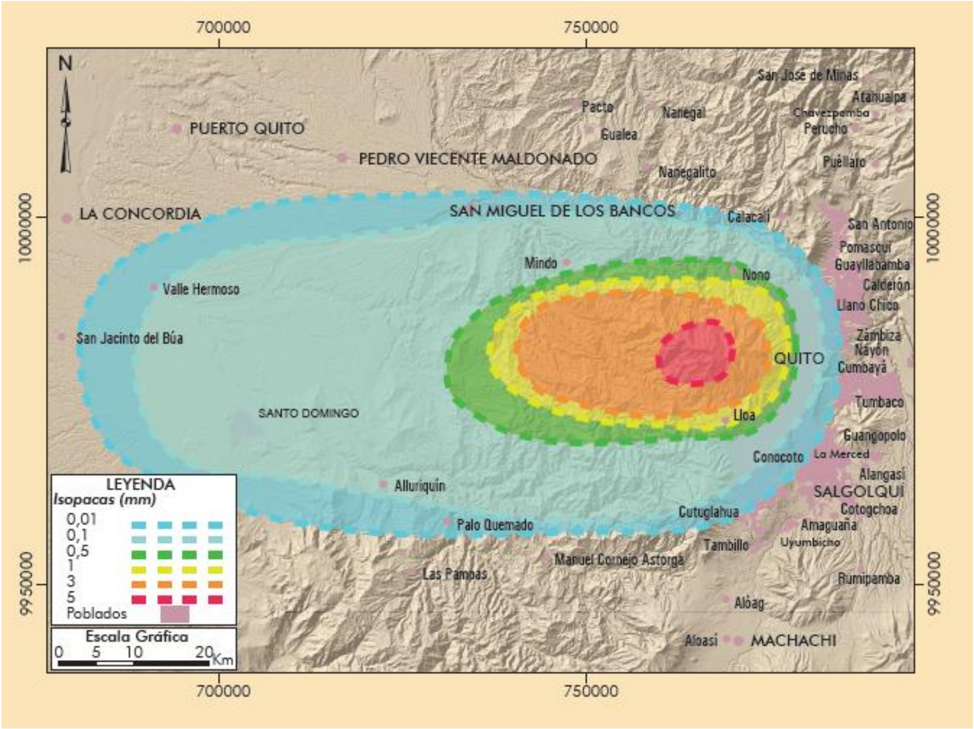
DETERMINISTIC APPROACH (FIELD DATA)



Guagua Pichincha: tephra fallout hazard assessment



- Multi-hazard map (2019)
- Tephra fallout hazard: modeling of 3 benchmark scenarios (1999-2001, AD 1660 and AD 970) with Ash 3D – DETERMINISTIC APPROACH WITH MULTIPLE SCENARIOS



Project objectives

Producing tephra fallout hazard maps for Cotopaxi and Guagua Pichincha and creating hazard curves for sensitive sites in Quito

By using the coupled PLUME-MoM/HYSPLIT model

By applying a *doubly stochastic approach* to quantify

Range of variation of input parameters for the model

Probability of occurrence of different eruption types

Under/Overestimation of the numerical model

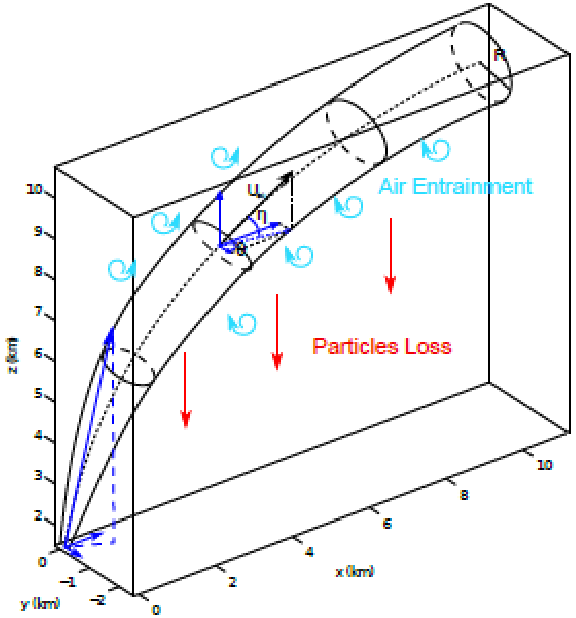
Define hazard maps/curves

Define uncertainty

Tephra fallout numerical modelling

PLUME-MoM

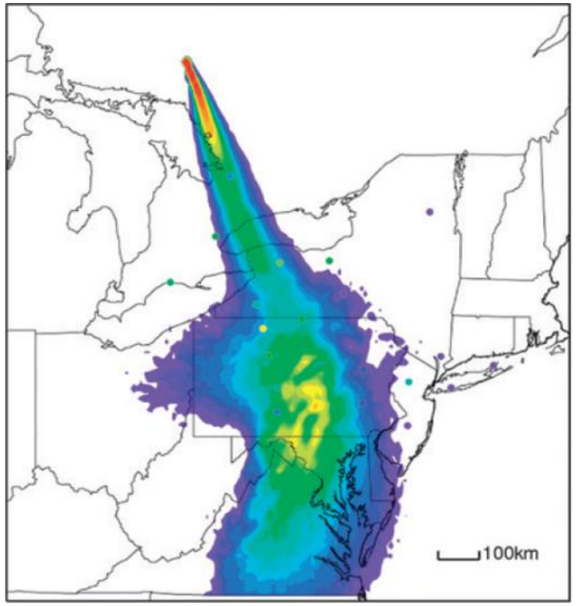
Eulerian integral model for the steady-state dynamic of a plume in a 3-D coordinates system



Initialisation

HYSPLIT

Hybrid model (Lagrangian-Eulerian) for tephra transport, dispersion and sedimentation



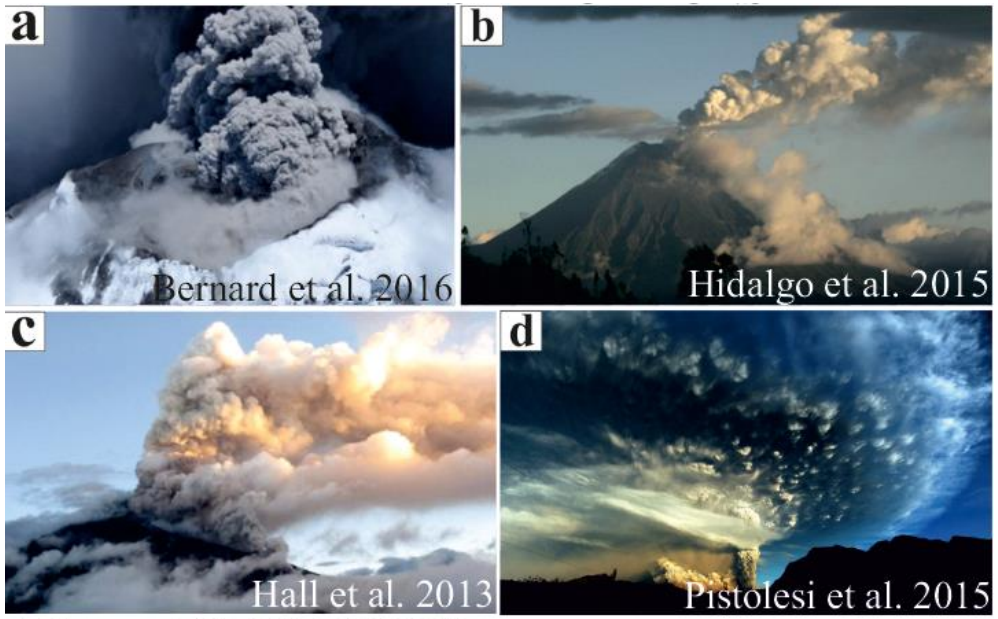
Point/surface sources

Coupling by F. Pardini e M. De'Michieli Vitturi

Uncertainty quantification

Tadini et al. (2020)

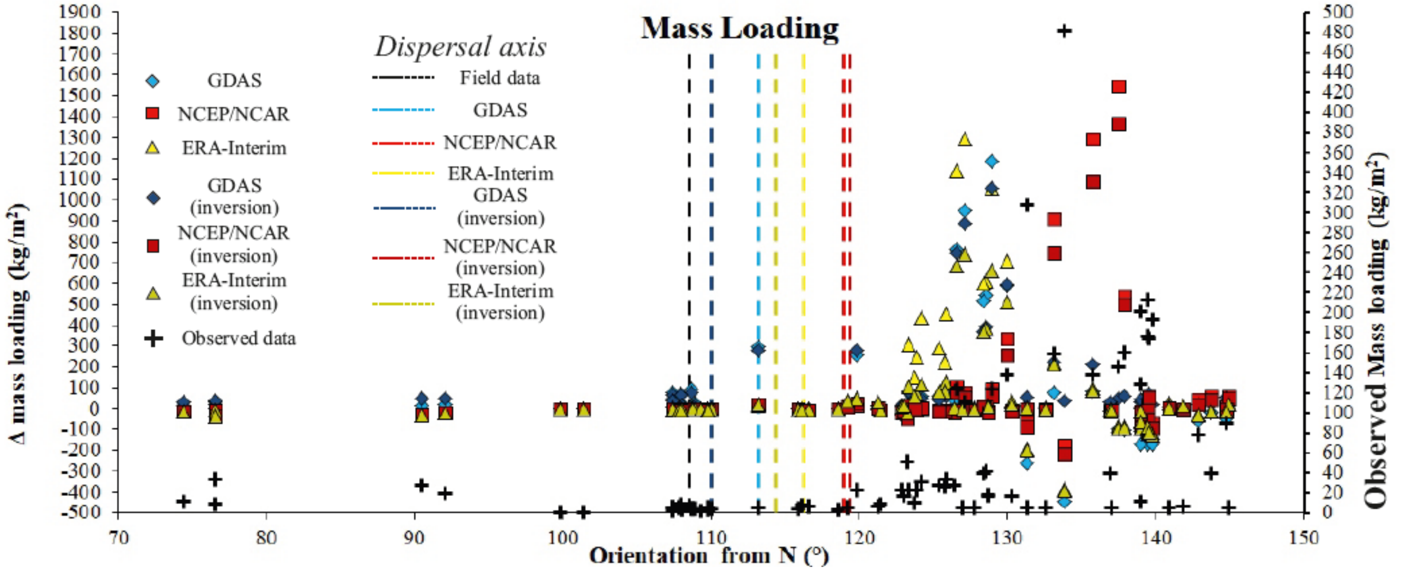
- With respect to plume height
- With respect to mass loading at specific sites
- With respect to grain size at specific sites



a) Cotopaxi (08/2015-12/2015) Hydrovolcanic/Ash emission
b) Tungurahua (14-30/07/2013) Violent Strombolian
c) Tungurahua (16/08/2006) SubPlinian
d) Cordòn Caulle (04-06/06/2011) SubPlinian

Uncertainty quantification of the model

Tadini et al. (2020)



AGU100 ADVANCING EARTH AND SPACE SCIENCE

JGR Solid Earth

RESEARCH ARTICLE
10.1029/2019JB018390

Quantifying the Uncertainty of a Coupled Plume and Tephra Dispersal Model: PLUME-MOM/HYSPLIT Simulations Applied to Andean Volcanoes

A. Tadini[1], O. Roche[1], P. Samaniego[1,2], A. Guillin[3], N. Azzaoui[3], M. Gouhier[1], M. de' Michieli Vitturi[4], F. Pardini[4], J. Eychenne[1], B. Bernard[2], S. Hidalgo[2], and J. L. Le Pennec[1,5]

[1]Laboratoire Magmas et Volcans, Université Clermont Auvergne, CNRS, IRD, OPGC, Clermont-Ferrand, France, [2]Instituto Geofisico, Escuela Politécnica Nacional, Quito, Ecuador, [3]Laboratoire de Mathématiques Blaise Pascal, Université Clermont Auvergne, CNRS, Clermont-Ferrand, France, [4]Istituto Nazionale di Geofisica e Vulcanologia, Pisa, Italy, [5]Institut de Recherche pour le Développement, Quito, Ecuador

$$\begin{cases} \dfrac{MO}{MML} = \dfrac{\frac{\sum_{i=1}^{N_o} \Delta_i}{N_o}}{\mu_{ML}} & for\ \Delta_i > 0 \\ \dfrac{MU}{MML} = \dfrac{\frac{\sum_{i=1}^{N_u} \Delta_i}{N_u}}{\mu_{ML}} & for\ \Delta_i < 0 \end{cases}$$

Mean Overestimation (MO)

Mean Underestimation (MU)

Mean Mass Loading (MML)

μ_{ML} = mean of the observed mass loading

Δ mass loading = $ML_{computed}$ - $ML_{observed}$

Δ_i = Δ mass loading for the i-esimal section

PLUME-MoM/HYSPLIT more suited for reproducing medium/large magnitude eruptions (sub-plinian or plinian)

Mean overestimation coefficient → **$MO/MML_{Cordón\ Caulle\ 2011}$ = 1.48**

Mean underestimation coefficient → **$MU/MML_{Cordón\ Caulle\ 2011}$ = -0.49**

Expert elicitation/1

WHY?

Prompt decision or a long term-planning are needed

BUT

- No (or very little) data available
- Data source are extremely uncertain

A complete quantification of uncertainty is required

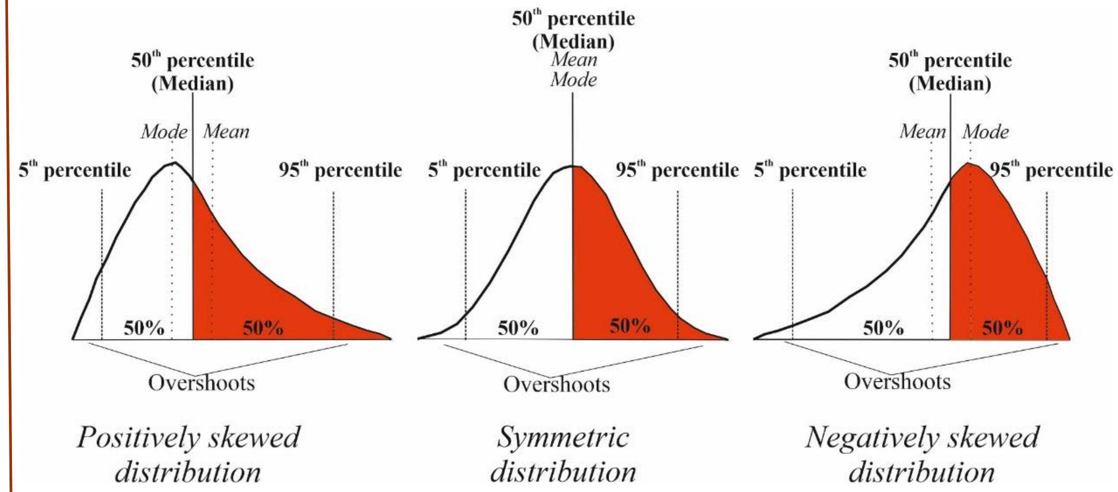
HOW?

The Classical Model

1. **Choosing the experts**
2. **Seed questions**
3. **Target questions**

Two questionnaires – median value with 5th and 95th percentiles

EACH EXPERT DEFINES A PROBABILITY DISTRIBUTION



«Scoring» method → *Weighted mean of experts' answers* → *« Decision maker »*

OUR STUDY

1. 20 experts
2. 14 seed questions
3. 55 Target questions – uncertainty range for:
   - Future eruption types (different periods)
   - Eruptive source parameters (duration, total mass, plume height)

Bulletin of Volcanology (2021) 83:35
https://doi.org/10.1007/s00445-021-01458-z

RESEARCH ARTICLE

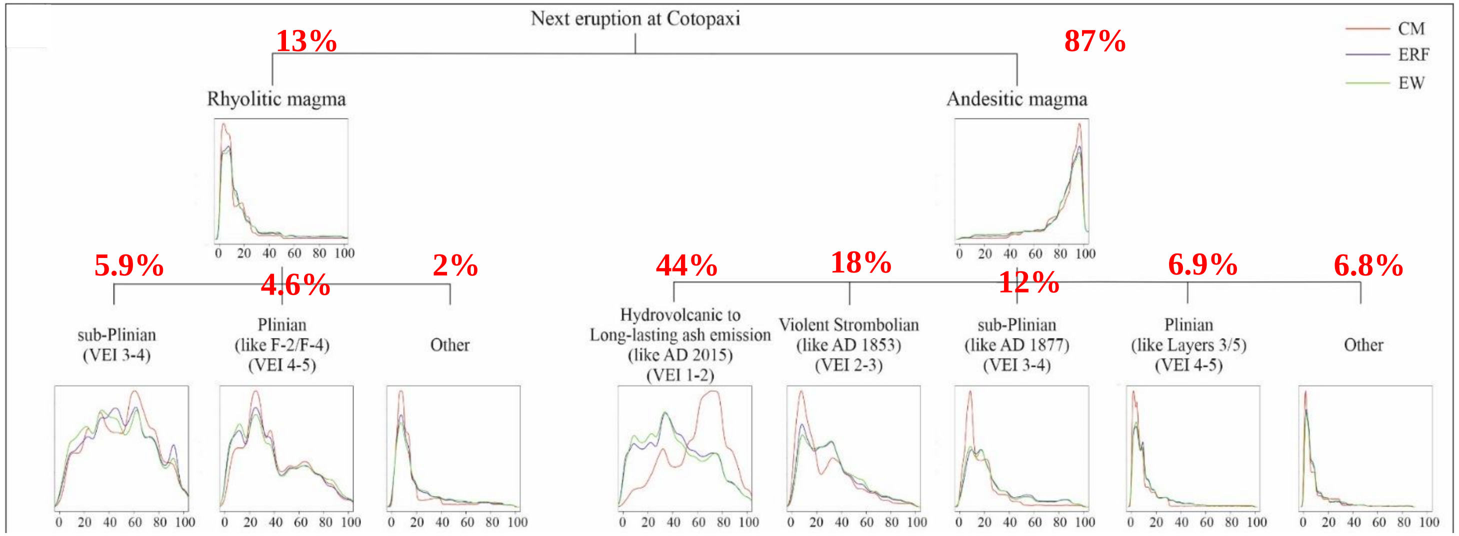
Eruption type probability and eruption source parameters at Cotopaxi and Guagua Pichincha volcanoes (Ecuador) with uncertainty quantification

Alessandro Tadini[1] · Olivier Roche[1] · Pablo Samaniego[1,2] · Nourddine Azzaoui[3] · Andrea Bevilacqua[4] · Arnaud Guillin[3] · Mathieu Gouhier[1] · Benjamin Bernard[2] · Willy Aspinall[5] · Silvana Hidalgo[2] · Julia Eychenne[1] · Mattia de' Michieli Vitturi[4] · Augusto Neri[4] · Raffaello Cioni[6] · Marco Pistolesi[7] · Elizabeth Gaunt[2] · Silvia Vallejo[2] · Marjorie Encalada[2] · Hugo Yepes[2] · Antonio Proaño[2] · Mia Pique[2,8]

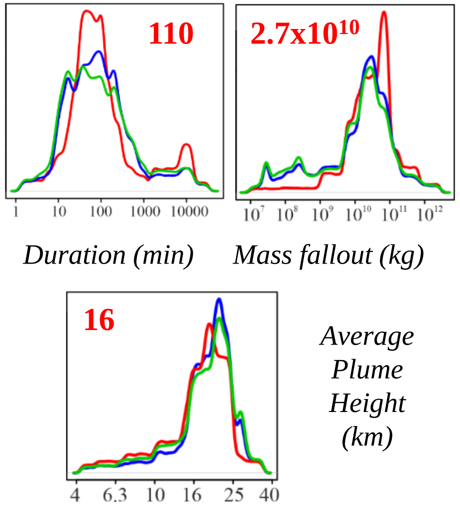
Received: 29 October 2020 / Accepted: 9 April 2021

Expert elicitation/2

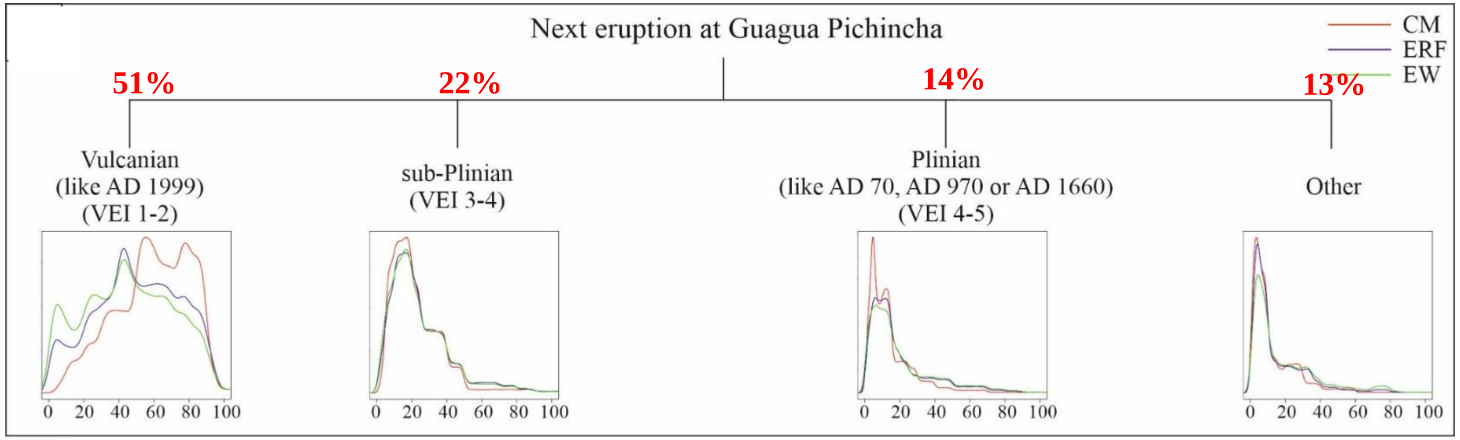
COTOPAXI



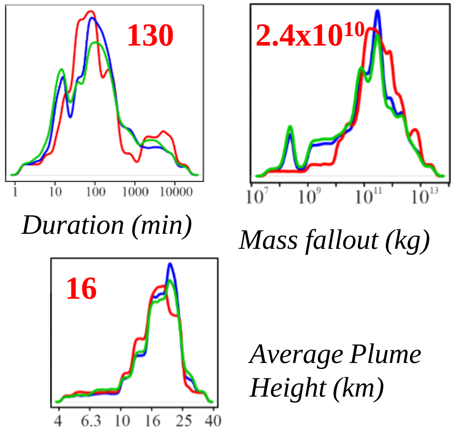
Sub-Plinian andesitic



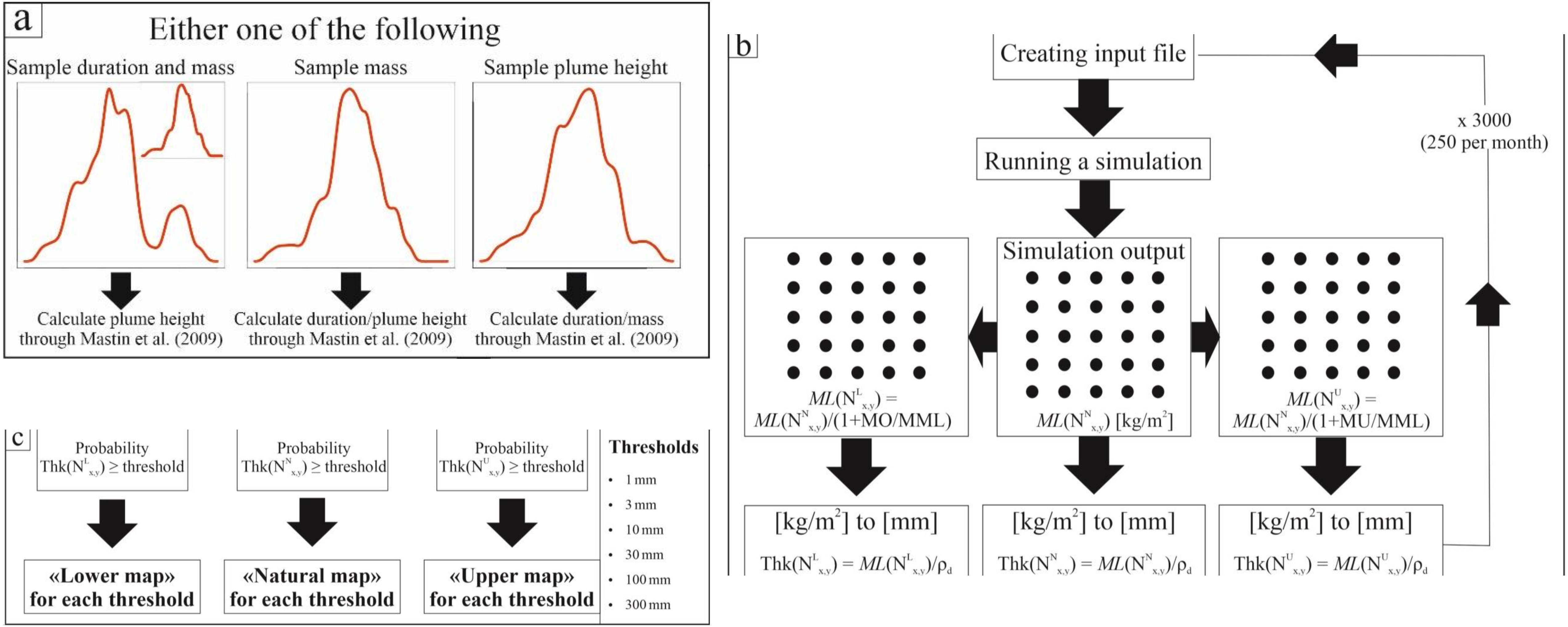
GUAGUA PICHINCHA



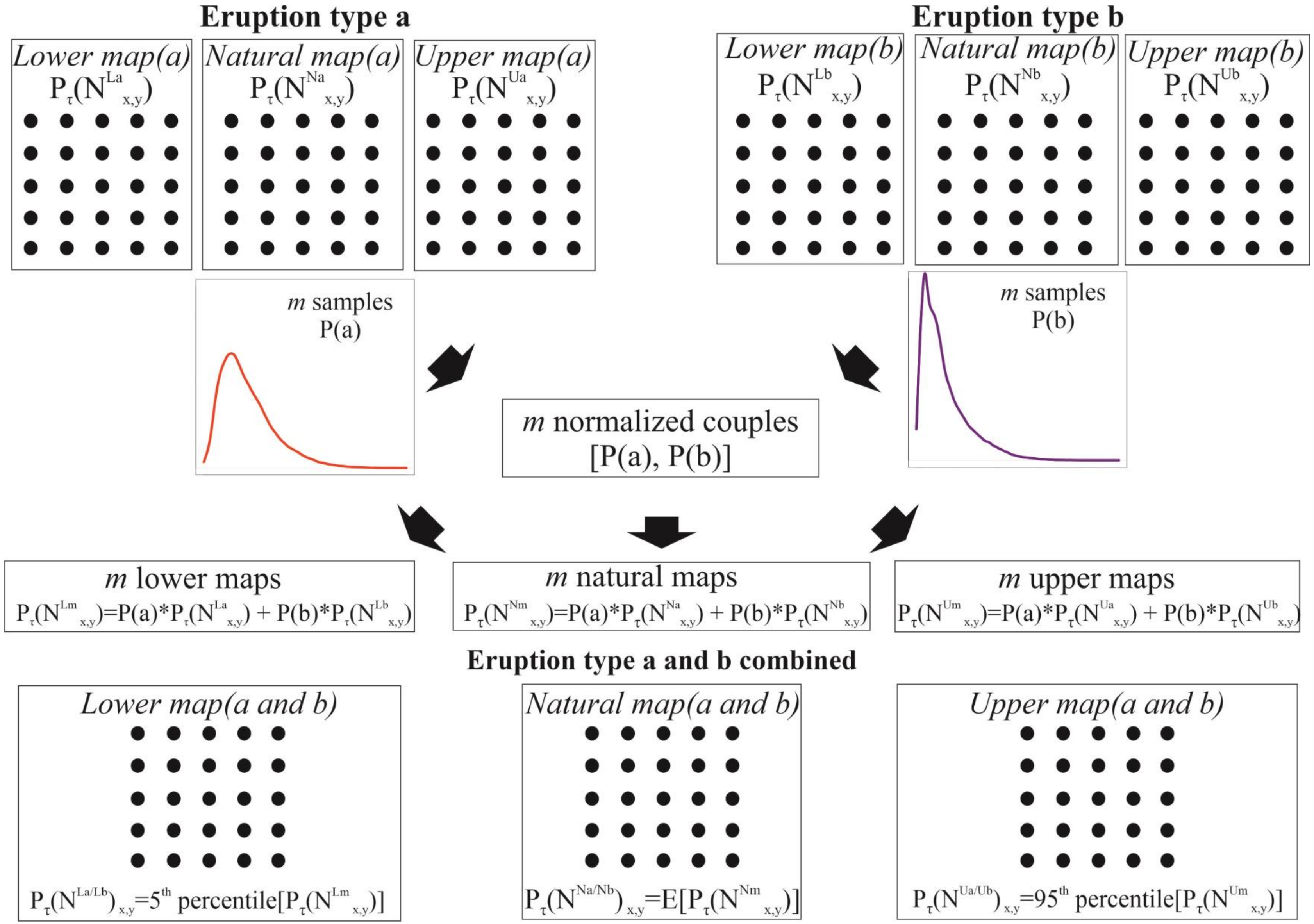
Sub-Plinian



Hazard maps production



Hazard maps production



Hazard maps

manuscript submitted to *Journal of Geophysical Research:Solid Earth*

Tephra fallout probabilistic hazard maps for Cotopaxi and Guagua Pichincha volcanoes (Ecuador) with uncertainty quantification

A. Tadini[1], N. Azzaoui[2], O. Roche[1], P. Samaniego[1,3], B. Bernard[3], A. Bevilacqua[4], S. Hidalgo[3], A. Guillin[2], M. Gouhier[1]

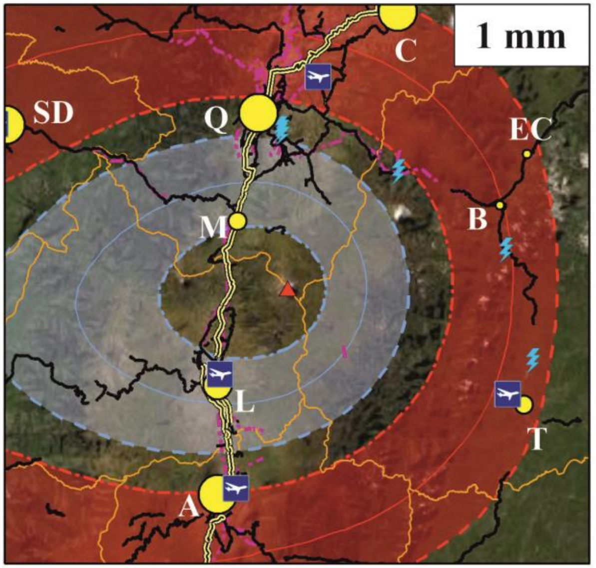
Hazard maps for sub-plinian and plinian eruptions considered individually or together:

- for Cotopaxi, rhyolitic (2) and andesitic (2) – *TOTAL 4*
- for Guagua Pichincha, dacitic (2) – *TOTAL 2*

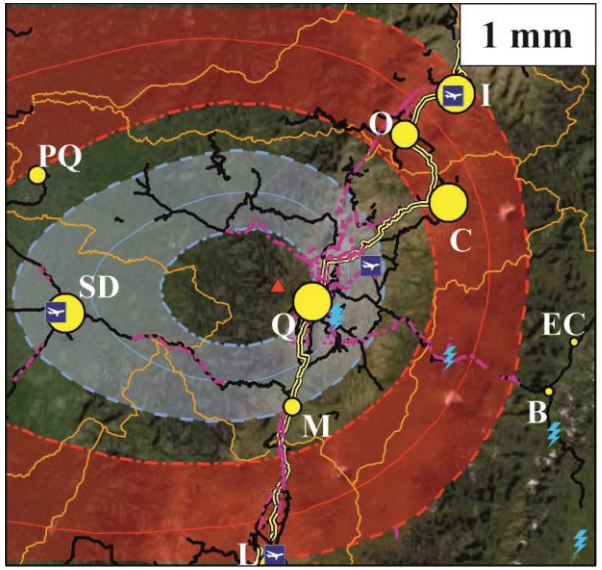
Given thickness thresholds (1 - 300 mm) and different probabilities

Given probability (10% and 50%) and different thickness thresholds

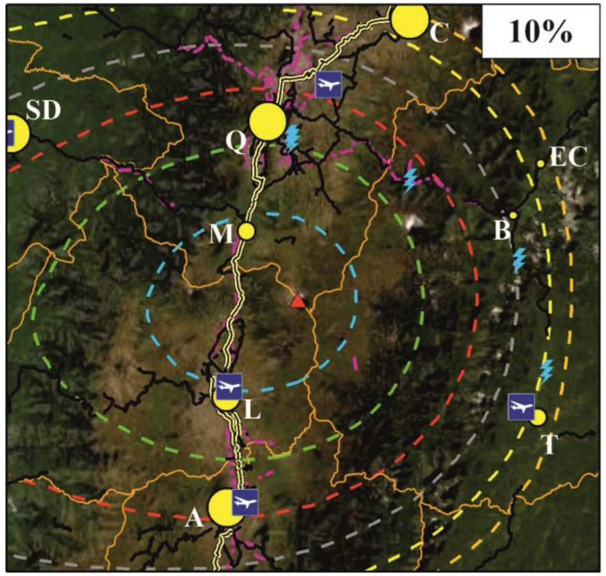
Cotopaxi



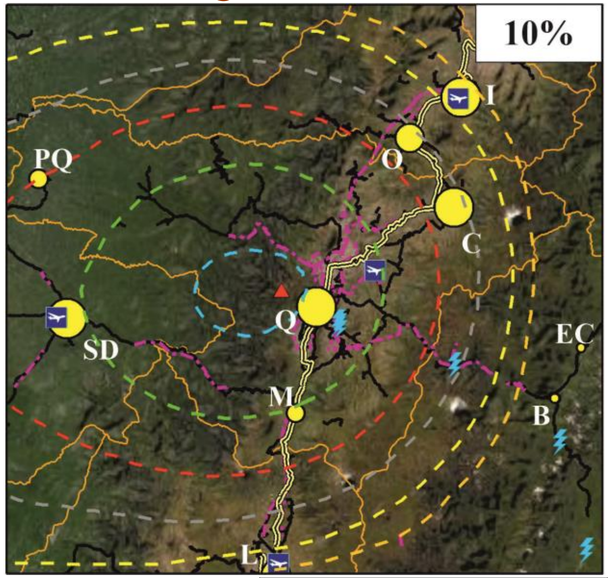
Guagua Pichincha

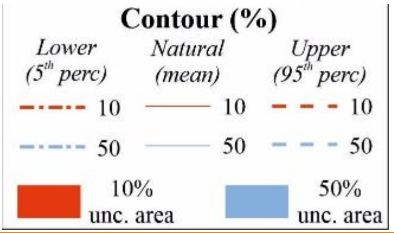


Cotopaxi



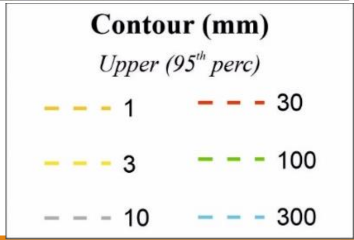
Guagua Pichincha





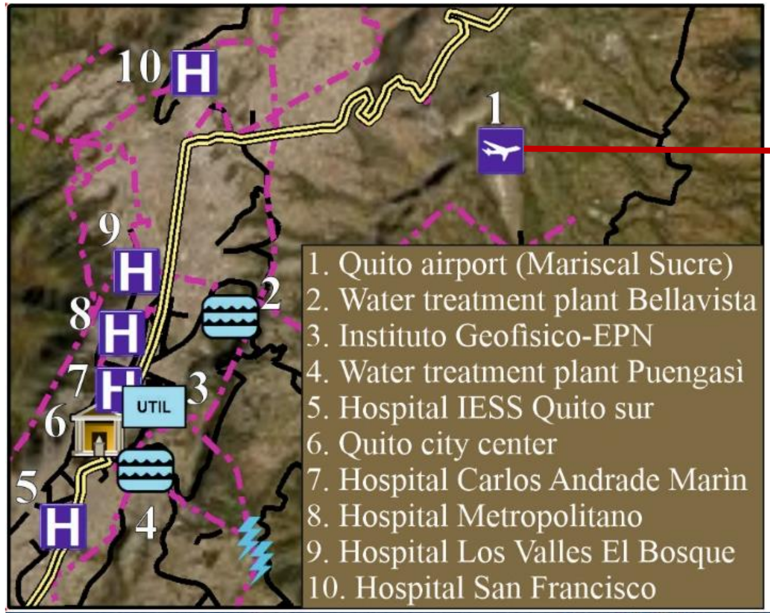
Surface (km²) of 1mm-10% → *Coto:* ***13k*** – ***20k*** – ***25k***
Pich: ***12k*** – ***19k*** – ***24k***

Population within 1mm-10% → *Coto:* ***2.2M*** – ***4.1M*** – ***4.4M***
Pich: ***3.3M*** – ***3.8M*** – ***4.1M***

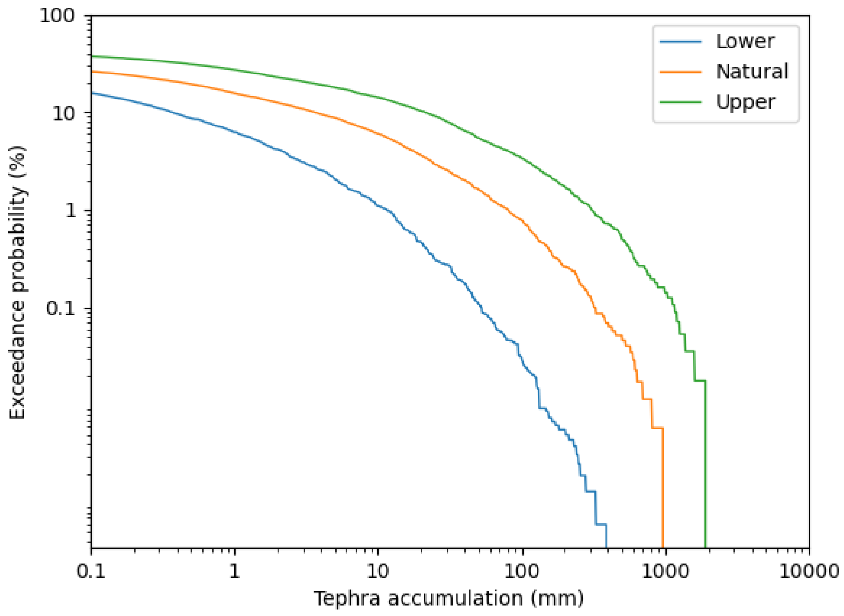


Hazard curves

For a more detailed study of the city of Quito : hazard curves for 10 sensitive sites

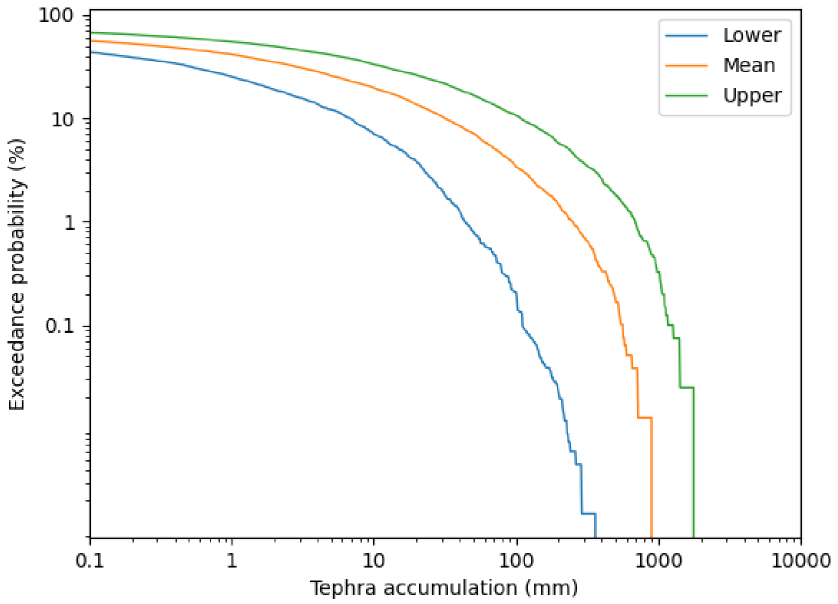


Cotopaxi



1mm : 6.4% - **15.9%** - 24.0%
3mm : 3.4% - **11.0%** - 18.0%
10mm : 1.3% - **6.3%** - 11.1%
30mm : 0.3% - **2.8%** - 6.1%
100mm : 0.1% - **0.8%** - 2.1%
300mm : 0 - **0.1%** - 0.4%

Guagua Pichincha



1mm : 26.3% - **41.3%** - 50.4%
3mm : 16.6% - **30.8%** - 40.2%
10mm : 7.9% - **19.6%** - 27.3%
30mm : 2.4% - **10.4%** - 16.2%
100mm : 0.3% - **3.4%** - 6.7%
300mm : 0 - **0.7%** - 1.7%

Conclusions

- **Uncertainty quantification of the model** – *definition of mean under/overestimation coefficientes of the model*

- **Uncertainty quantification** for the probability of occurrence of different **eruption types** for the range of **eruptive source parameters** – *expert elicitation session*

- **Hazard maps** produced for sub-plinian and plinian eruptions considered separately and together
  - **Cotopaxi** (4 eruption types)
  - **Guagua Pichincha** (2 eruption types)

- Two map types:
  1. for a given **tephra accumulation threshold** and different probabilities
  2. for a given **probabilité donnée et différents seuils d'accumulation de téphra**

- Three maps (« lower », « natural » et « upper ») that quantify the different sources of uncertainty

- **Quito : hazard curves** defined for **10 sensitive sites**

Thanks for your attention!