IV CONFERENZA

RITTMANN «GIOVANI RICERCATORI»

Tephra fallout hazard assessment with uncertainty quantification: a case study from Cotopaxi and Guagua Pichincha volcanoes, Ecuador

Alessandro Tadini

09/04/2021

O. Roche, P. Samaniego – LMV
N. Azzaoui – LMBP
B Bernard, S. Hidalgo – IG Quito
A. Bevilacqua, M. de' Michieli Vitturi – INGV Pisa

W. Aspinall, A. Guillin, M. Gouhier, J. Eychenne, F. Pardini, J. L. Le Pennec, A. Neri, R. Cioni, M. Pistolesi, E. Gaunt, S. Vallejo, M. Encalada, H. Yepes, A. Proaño, M. Pique

I-SITE project

PROJECT AIM

Creation of probabilistic tephra fallout hazard maps for Cotopaxi and Guagua Pichincha volcanoes

with a specific focus on the city of Quito

NOVELTIES

Employment of a numerical model (PLUME-MoM / HYSPLIT) never used for producing probabilistic tephra fallout hazard maps

Explicit quantification of major source of uncertainty

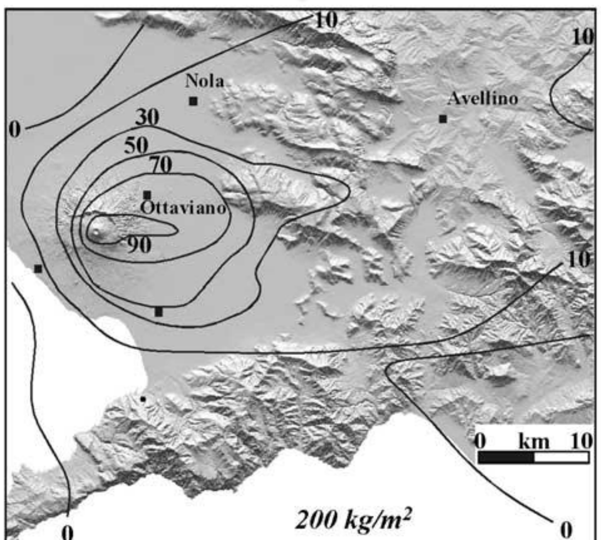
1. Of the numerical model
2. Of the probability of having different eruptions
3. Of the eruptive source parameters

→ ***Expert elicitation***

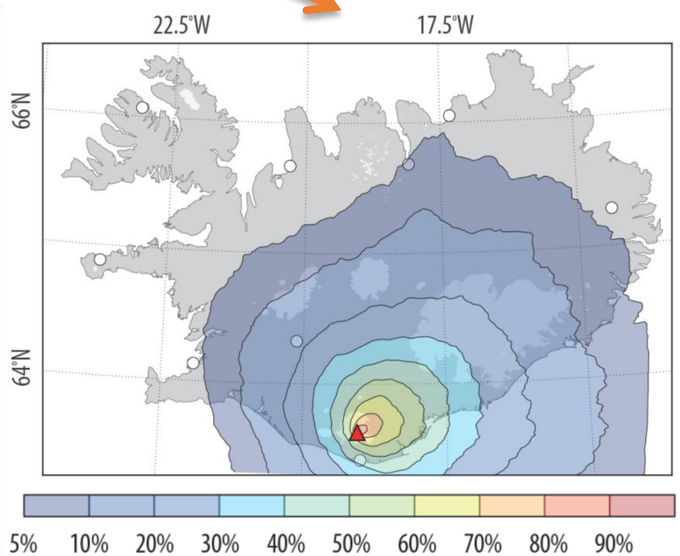
Introduction

Tephra fallout hazard assessment

- As a function of mass loading (kg/m^2 or g/cm^2) or thickness (cm or mm)
- With a deterministic, semi-probabilistic or probabilistic approach
- By using field data or numerical modelling



Cioni et al., 2003



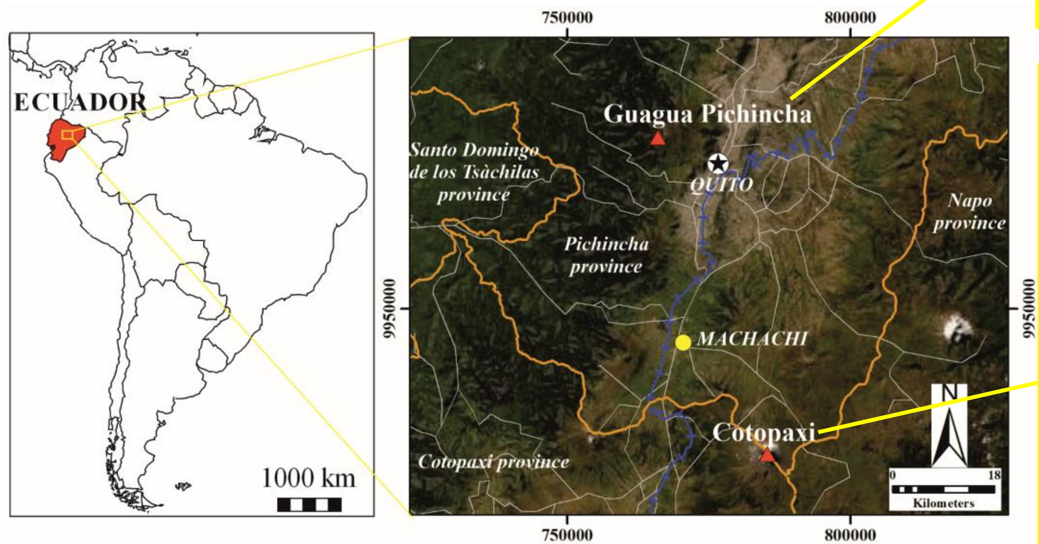
Biass et al., 2014

Aleatoric and epistemic uncertainty during hazard map production

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

Significance of the project: Ecuador and Quito region

- 21 active volcanoes in Ecaudor (Holocene activity)
- Quito threatened by several active volcanoes
- Several studies to produce tephra fallout hazard maps but:
  - a probabilistic approach has not always been used
  - quantification of uncertainty has not always been applied



GUAGUA PICHINCHA

- ~16 km W of Quito
- Dacitic to andesitic volcanism
- Cycles of dome growth and final explosive eruptions
- Last eruption in AD 1999-2001

COTOPAXI

- ~60 km S of Quito
- Bimodal volcanism (andesitic and rhyolitic)
- Different eruptive styles (mostly explosive)
- Last eruption in AD 2015

Numerical modelling and uncertainty quantification

Tephra fallout numerical modelling

PLUME-MoM

Eulerian integral model for the steady-state dynamics in a 3-D coordinate system

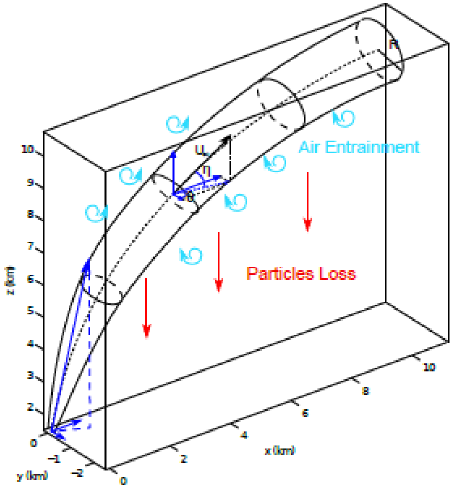
HYSPLIT

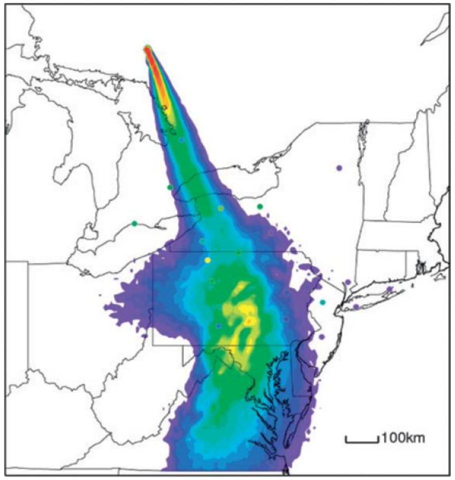
Hybrid (Lagrangian-Eulerian) TTDM

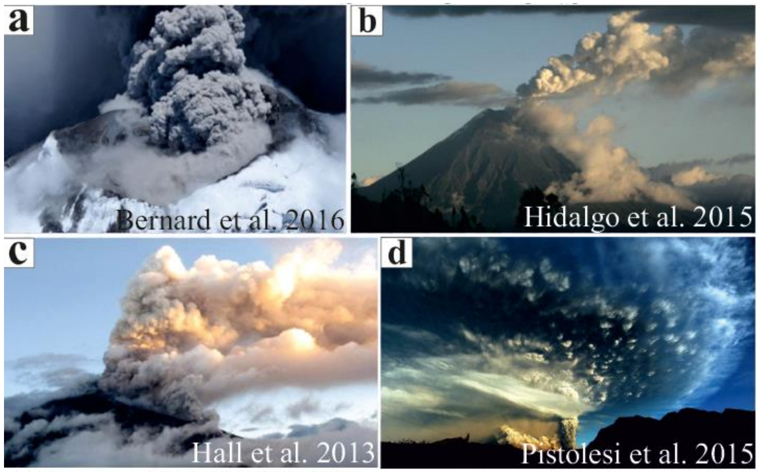
Uncertainty quantification

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





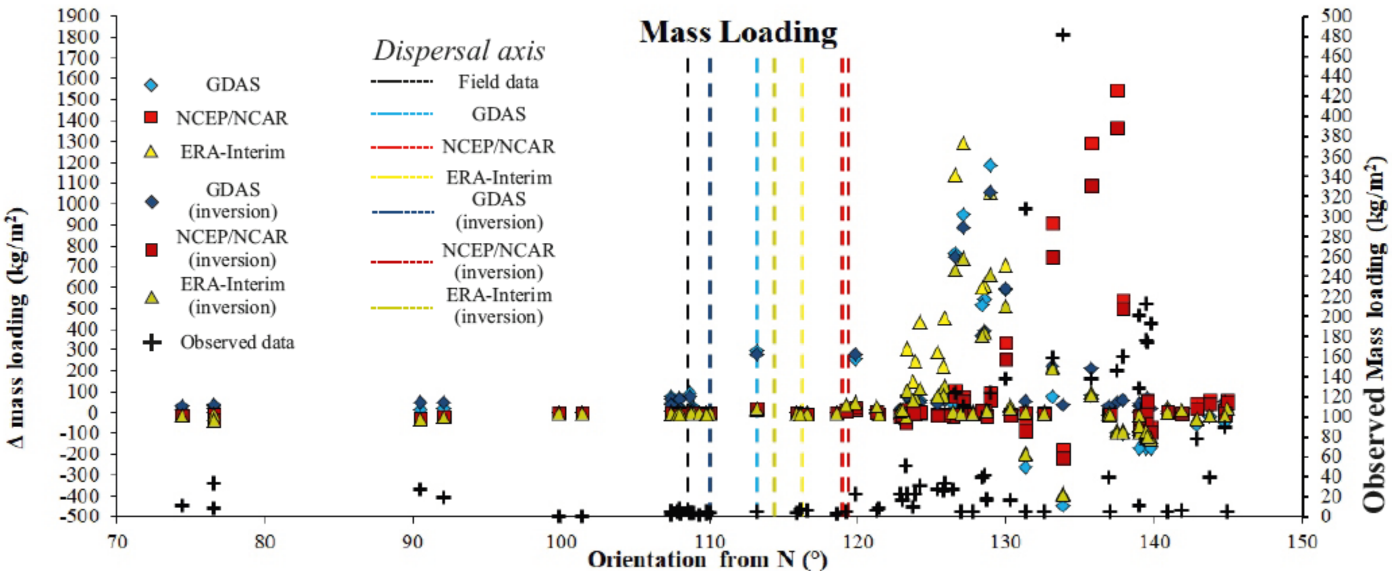


a) Cotopaxi (08/2015-12/2015) Hydrovolcanic/Ash emission
b) Tungurahua (14-30/07/2013) Violent Strombolian
c) Tungurahua (16/08/2006) SubPlinian
d) Cordòn Caulle (04-06/06/2011) SubPlinian

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

Model uncertainty quantification

Tadini et al. (2020)



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

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 best suited for larger magnitude eruptions (sub-Plinian or Plinian).

$MO/MML_{Cordón\ Caulle\ 2011}$ = 2.20

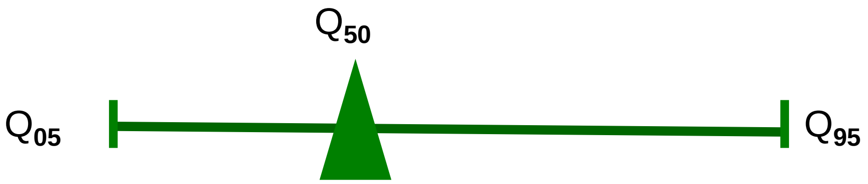
$MU/MML_{Cordón\ Caulle\ 2011}$ = -0.12

Expert Elicitation

HOW?

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

For each question - median value with two upper and lower limits of uncertainty (usually 5 ° and 95 ° percentile)



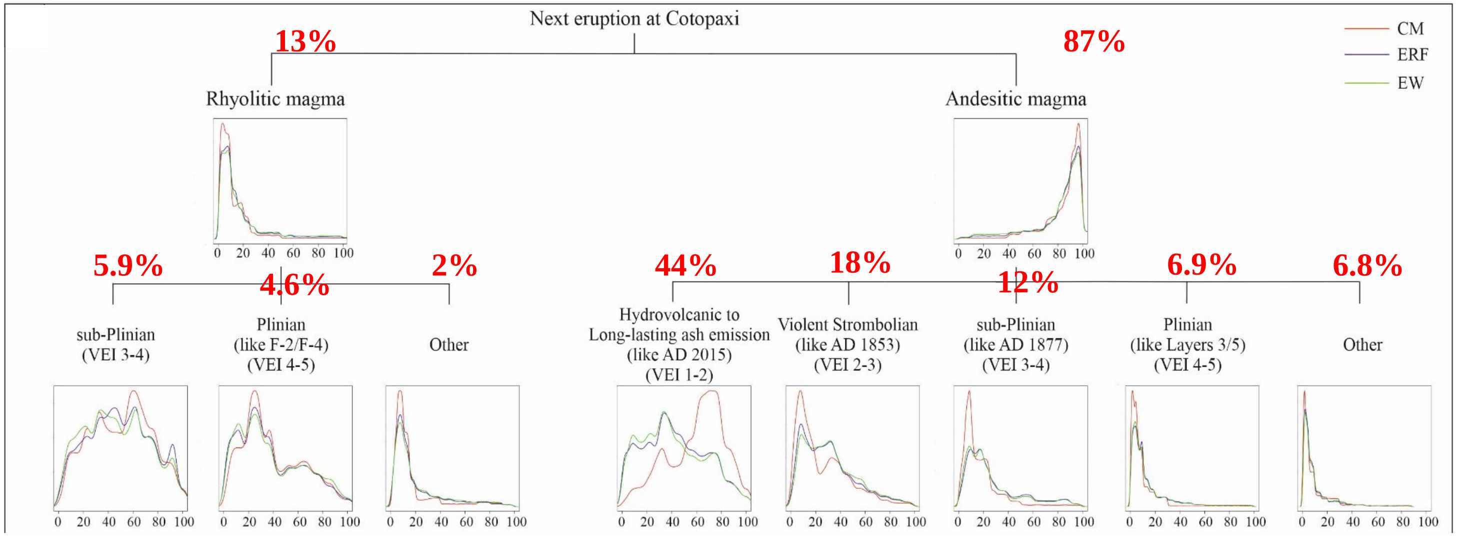
Different scoring methods which consider:

- Calibration (accuracy): the extent to which expert assessments match actual values
- Informativeness (precision): degree of concentration of distribution

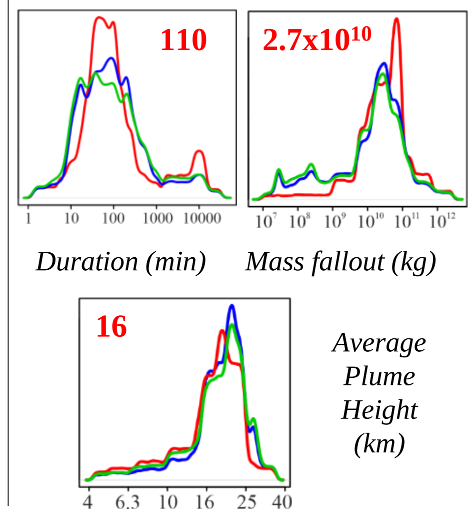
OUR STUDY

1. 20 experts (different nationalities, background, experiences)
2. 14 seed questions
   - South american volcanism
   - Plume/tephra dispersal numerical modelling
3. 55 Target questions – uncertainty range for:
   - Future eruption types (different time frames)
   - Eruptive source parameters (duration, mass fallout, PH)

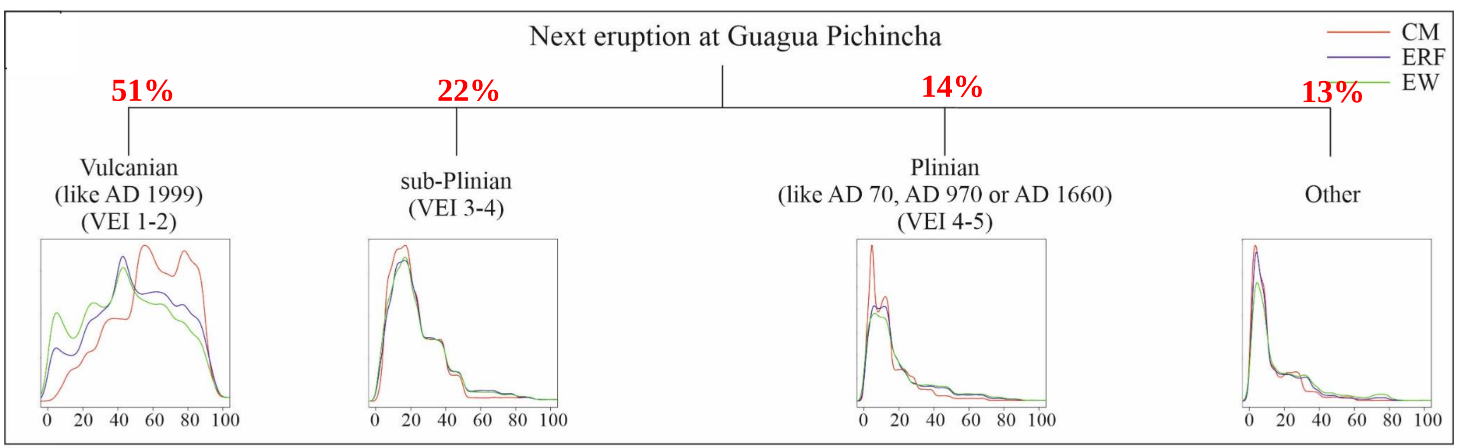
COTOPAXI



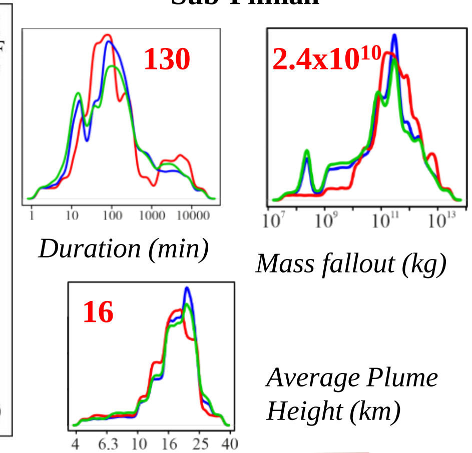
Sub-Plinian andesitic



GUAGUA PICHINCHA



Sub-Plinian



Tadini et al., Tephra fallout hazard assessment with uncertainty quantification: a case study from Cotopaxi and Guagua Pichincha volcanoes, Ecuador

Maps and hazard curves

Hazard maps production

Eruption type i

Uncertainty Input parameters .... Creating input file

- GDAS meteo data (12/2004-12/2019)

- Parameters – triangular distributions on elicited percentiles:
  - Eruption duration
  - Mass flow rate (total fallout mass/duration)
  - Average plume height (for TGSD with magma viscosity)

One parameter sampled, the other two calculated according to Mastin et al. (2009)

- Parameters – uniform distributions:
  - Particle densities
  - Initial water mass fraction of magma
  - Particle shape factor

- TGSD according to Costa et al. (2016)

Hazard maps and curves format

Maps for sub-Plinian and Plinian eruptions considered individually and together:

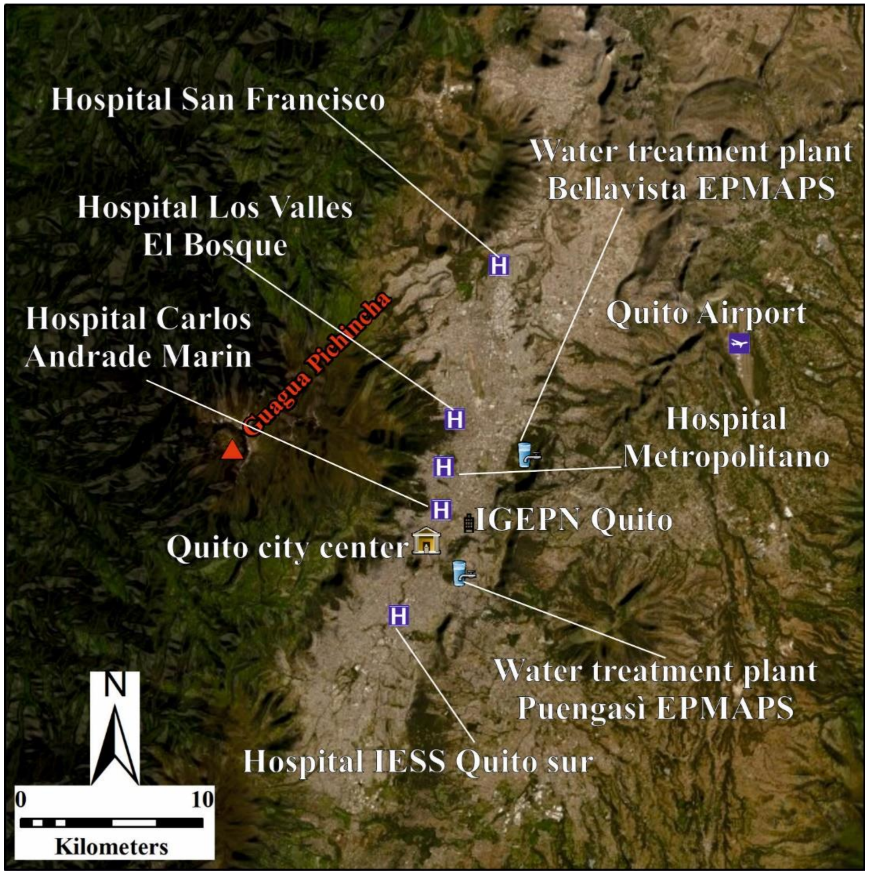
- for Cotopaxi, rhyolitic (2) and andesitic (2) – *TOTAL 4*
- for Guagua Pichincha, dacitic (2) – *TOTAL 2*

Maps:

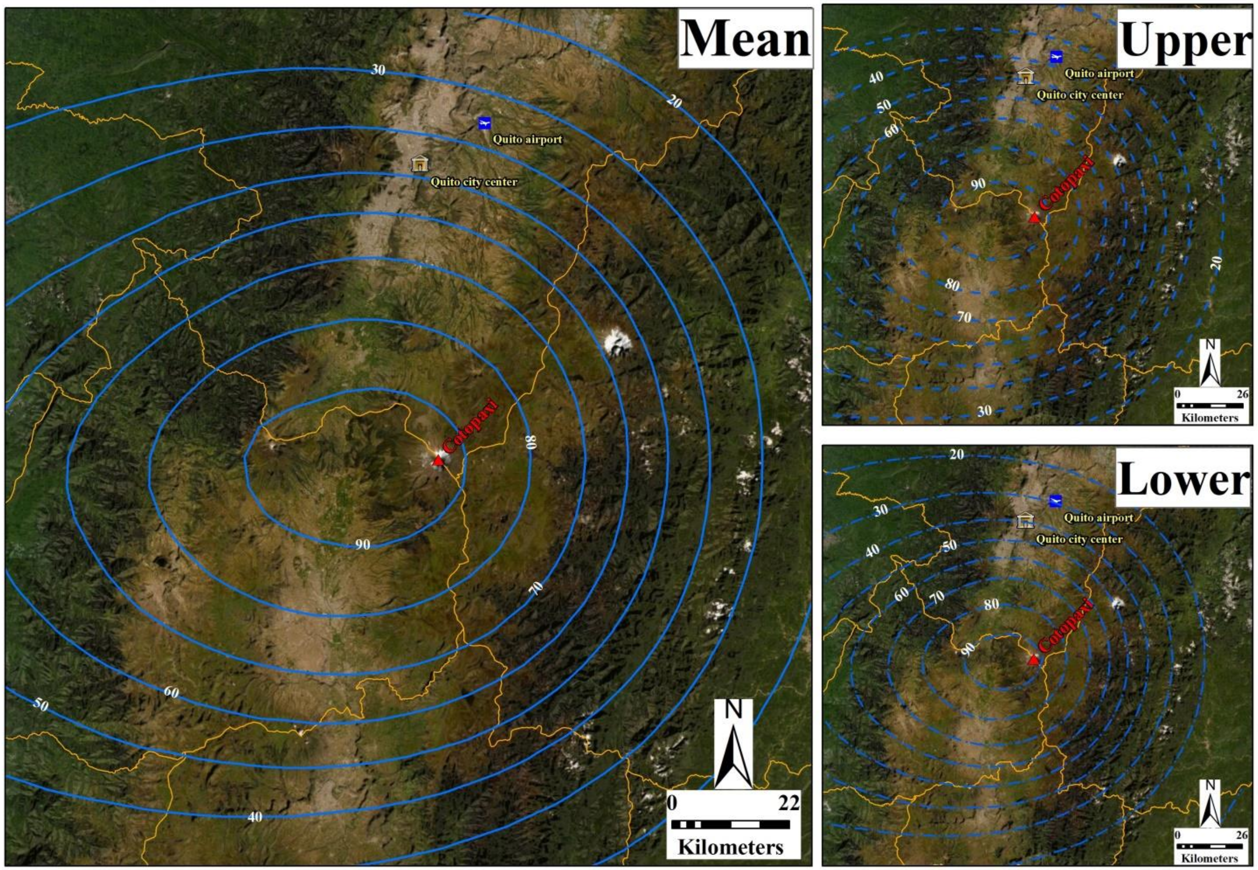
1. For a given tephra accumulation threshold (1, 3, 10, 30, 100, 300 mm) and different probabilities;
2. For a given probability (10% and 50%) and different tephra accumulation thresholds;

For a more detailed study on the city of Quito:

- Hazard curves for 10 sensitive sites
  - Quito airport
  - IGEPN
  - City center
  - 5 hospitals
  - 2 water treatment plants



Cotopaxi



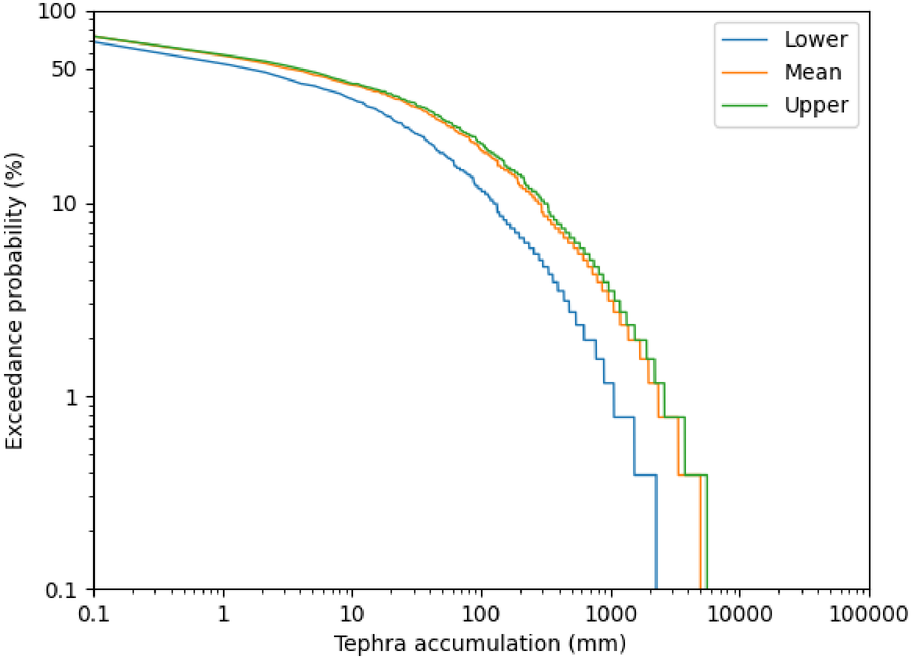
Probability contours – 1 mm

Surface (km^2) of 70%: ***4174*** – ***5838*** **-** ***6128***

Total population within 70% (LandScan™ data): ***0.014M*** – ***0.36M*** – ***0.40M***

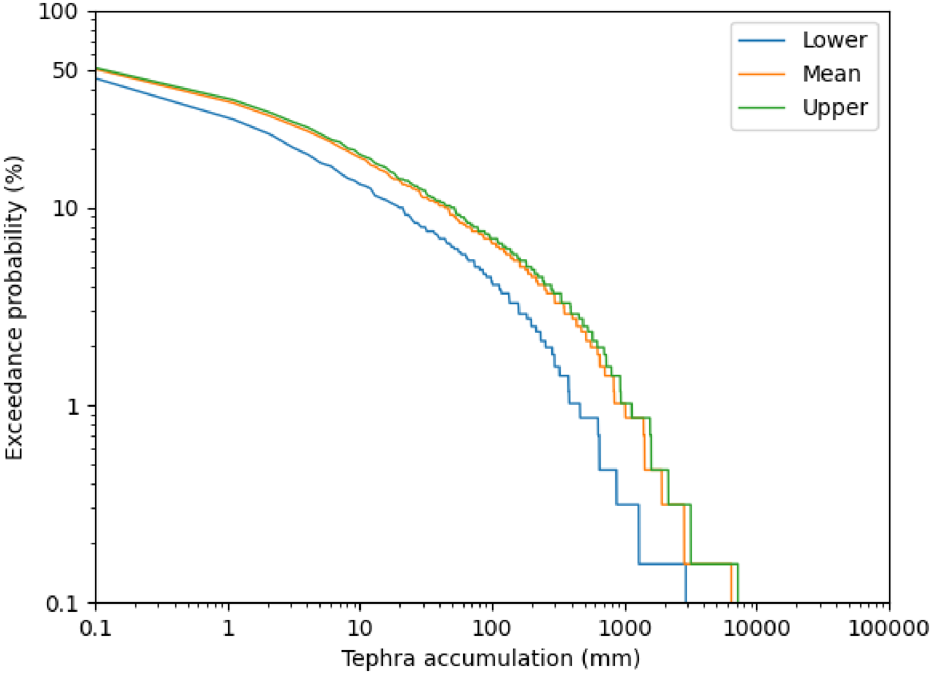
Hazard Curves - QUITO AIRPORT

Guagua Pichincha



1mm : 53.8% - **59.2%** - 59.8%
3mm : 44.5% - **50.3%** - 51.9%
10mm : 34.7% - **41.0%** - 41.7%
30mm : 23.3% - **31.8%** - 33.2%
100mm : 11.9% - **18.9%** - 20.3%
300mm : 5.1% - **8.9%** - 10.3%

Cotopaxi



1mm : 29.8% - **35.6%** - 36.8%
3mm : 20.5% - **26.5%** - 27.6%
10mm : 13.2% - **17.9%** - 18.6%
30mm : 8.0% - **11.3%** - 12.3%
100mm : 4.2% - **6.6%** - 7.0%
300mm : 1.5% - **3.3%** - 3.7%

Tadini et al., Tephra fallout hazard assessment with uncertainty quantification: a case study from Cotopaxi and Guagua Pichincha volcanoes, Ecuador

Conclusions

- Quantification of model uncertainty - *definition of coefficients for average overestimation/underestimation of the model*

- Quantification of uncertainty for the probability of occurrence of different types of eruption and the range of variation of the eruptive source parameters - *expert elicitation session*

- Hazard maps produced for Plinian and Sub-Plinian eruptions considered individually and together
  - Cotopaxi (4 eruption types)
  - Guagua Pichincha (2 eruption types)

- Two different types map types:
  1. for a given tephra accumulation threshold and different probabilities
  2. for a given probability and different thresholds of tephra accumulation

- Each type of map is presented as a set of three maps ("lower", "mean" and "upper") which quantify the three main sources of uncertainty

- For a more detailed study of the city of Quito, hazard curves were defined for 10 sensitive sites in the city

Thank you for your attention