BET_VH probabilistic assessment of pyroclastic flows hazard at El Misti volcano, South Peru, based on geological record and numerical simulations with TITAN2D

[1] Robert Constantinescu, [2] Jean - Claude Thouret, [3] Laura Sandri, [1] Ioan Aurel Irimus, [4] Ramona Stefanescu

INTRODUCTION

Fig.1. Panoramic view of Misti and city of Arequipa (http://www.ascentbuilders.com)

Pyroclastic density currents, which include pyroclastic surges and pyroclastic flows (PFs), are among the most dangerous volcanic phenomena. We present a probabilistic hazard assessment of the PFs generated from the collapse of eruptive column at El Misti volcano (5822 m) in South Peru (Fig.1). Misti is known for eruptions ranging in size from Vulcanian (e.g. 1440 – 1470 AD) to sub-Plinian (e.g. c.2030 BP) and Plinian (c.14,000, c.25,000, c.34,000 yr BP).The high relief of the cone, the location of the city of Arequipa (~1,000,000 people) on two wide volcanoclastic fans and the H (3.5 km)/L (17 km) ratio (between the summit and the city center, make PFs a direct threat.

We use a Bayesian probabilistic approach with BET_VH software. We consider three eruption scenario sizes: *small Vulcanian/Phreatomagmatic* (VEI 2), *medium Sub-Plinian* (VEI 3-4), and *large Plinian* (VEI 4+). Quantitative data that stem from numerical simulations from TITAN2D (termed prior models) and from stratigraphic record (termed past data) are input to BET_VH, which enables us to compute the probabilities (in a 1-year time window) of **(i)** having an eruption **(ii)** in a selected location/vent **(iii)** of a specific size, **(iv)** and that this eruption will produce PFs **(v)** that will reach a location of interest around El Misti.

INPUT

NODES 1; 2; 3; 4; 5; 6

N1 - UNREST / NO UNREST

- past data: - 14 unrest / 110 y

$P(u) = 13.5\ \%$ / year

N2 - TYPE (degassing, tectonic, magmatic)

- past data: - 2 degassing; 12 tectonic; 0 magmatic

$P(d) = 18\%/y$; $P(t) = 76\%/y$; $P(m) = 6\%/y$

N3 - ERUPTION / NO ERUPTION

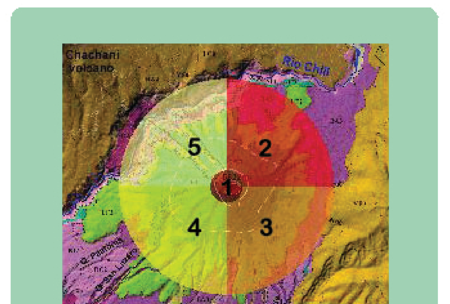
- prior distribution for an eruption due to magmatic unrest: $P(e) = 50\%/y$; $P(non\ e) = 50\%/y$

$P(1,2,3) = P(u) \times P(m) \times P(e) = 0.0039/y$

N4 - LOCATION

- 5 locations with prior distribution:

$P(loc1) = 0.9/y$; $P(loc2) = 0.2/y$; $P(loc3) = 0.1/y$; $P(loc\ 4) = 0.1/y$; $P(loc\ 5) = 0.6/y$



N 4 - Defined vent locations for Misti

N5 - SIZE

1 - Vulcanian / Phreatomagmatic (VEI 2) - $P(v) = 0.6/y$
2 - Sub - Plinian (VEI 3 - 4) - $P(s) = 0.3/y$
3 - Plinian (VEI 4+) - $P(p) = 0.1/y$

- past data: - 4 vulcanian; 1 sub-Plinian; 2 Plinian

N6 - PHENOMENA

- ***Pyroclastic flows:***

$P(v) = 0.1/y$ $P(s) = 0.5/y$ $P(p) = 0.7/y$

AUTHORS AFFILIATION

(1) Babes – Bolyai University, Faculty of Geography, Clinicilor no. 5 -7, 400006, Cluj – Napoca, Romania

(2) PRES Clermont , Université Blaise Pascal, Laboratorie Magmas et Volcans, UMR 6524 CNRS et IRD, 5 rue Kessler, 63038 Clermont - Ferrand CEDEX, France

(3) Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Bologna, via Donato Creti, 12, 40128 Bologna, Italy

(4) Department of Mechanical and Space Engineering, University at Buffalo, Buffalo, N.Y., U.S.A.

METHODS

For the hazard assessmnet, we used the extent of past PFs deposits at Misti (Node 7) together with TITAN2D simulations within BET_VH software in order to obtain conditional and absolute probabilities for any given PFs to reach a location of interest around the cone.

• BET_VH - Bayesian Event Tree for Volcanic Hazard (Fig.2) - is a probabilistic tool to calculate and visualize long-term probabilistic volcanic hazard assessment (Marzocchi et al. 2010).

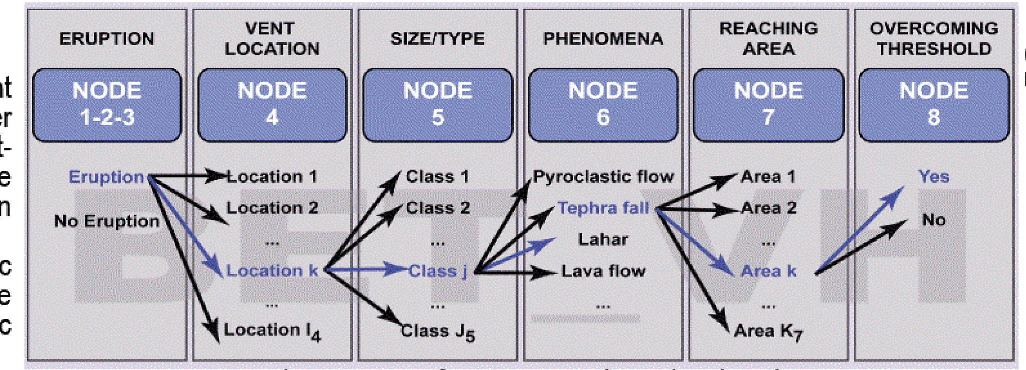


Fig.2 Graphic representation of BET_VH event tree (Marzocchi et al. 2010)

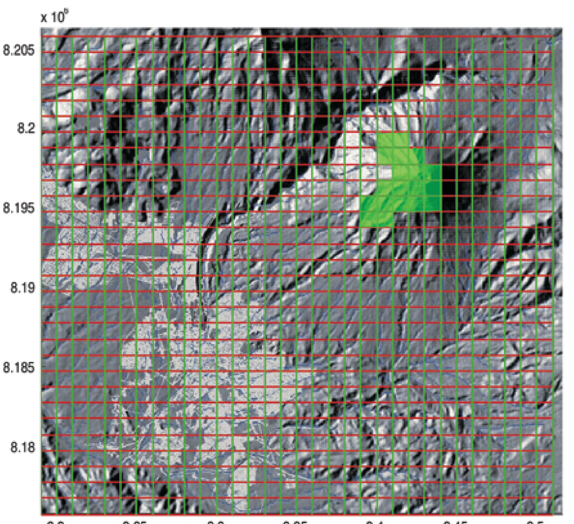
• BET merges all kinds of volcanological information to obtain probabilities of any relevant volcanic event (Marzocchi et al., 2007); the result is a long-term probabilistic estimate of the hazard posed by different volcanic hazardous processes (Marzocchi et al., 2010);

TITAN2D SIMULATIONS

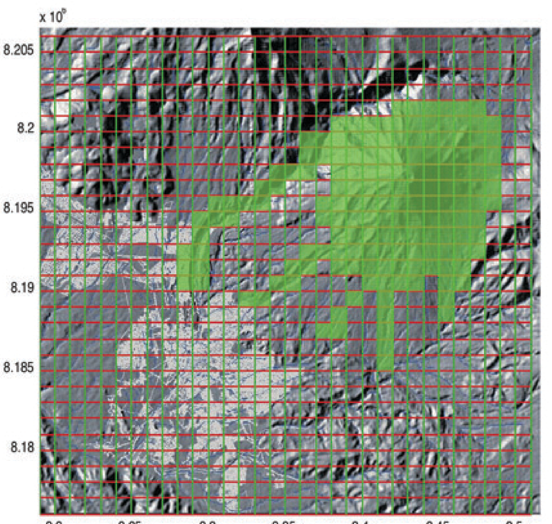
The simulated volumes of PFs are gradually increasing from $1 \times 10^6\ m^3$ for a Vulcanian event, up to $3 \times 10^9\ m^3$ for a Plinian eruption. The flow parameters were tested in accordance with those used in other studies (Procter et al. 2010, Sulpizio et al. 2010, Murcia et al. 2010, Vargas et al. 2010, Sheridan et al. 2005) and callibrated with the spatial extension of the past PFs deposits at Misti. We used a constant friction angle of 35° and variable bed friction angles from 22° for Vulcanian flows to 14° for Subplinian and 11° for Plinian. The initial velocities of the flows from the collapsing column were extracted with the formula $V = (2gh)^{1/2}$ and we tested the Vulcanian flows with 98m/s, the Subplinian with 140m/s and Plinian with 198 m/s. Here we present 5 selected simulations per scenario (1,3,5,7,10).

NODES 7; 8

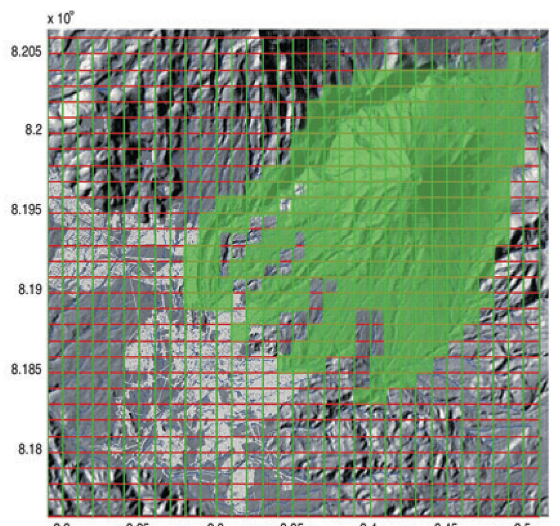
Past Data represented by the spatial extension of PFs deposits from the ~ 1440 A.D, ~ 2030 - 2050 B.C, ~ 14.000 B.C, ~ 25.000 B.C and 34.000 B.C eruptions.



PFs deposits from ~ 1440 A.D. Vulcanian eruption

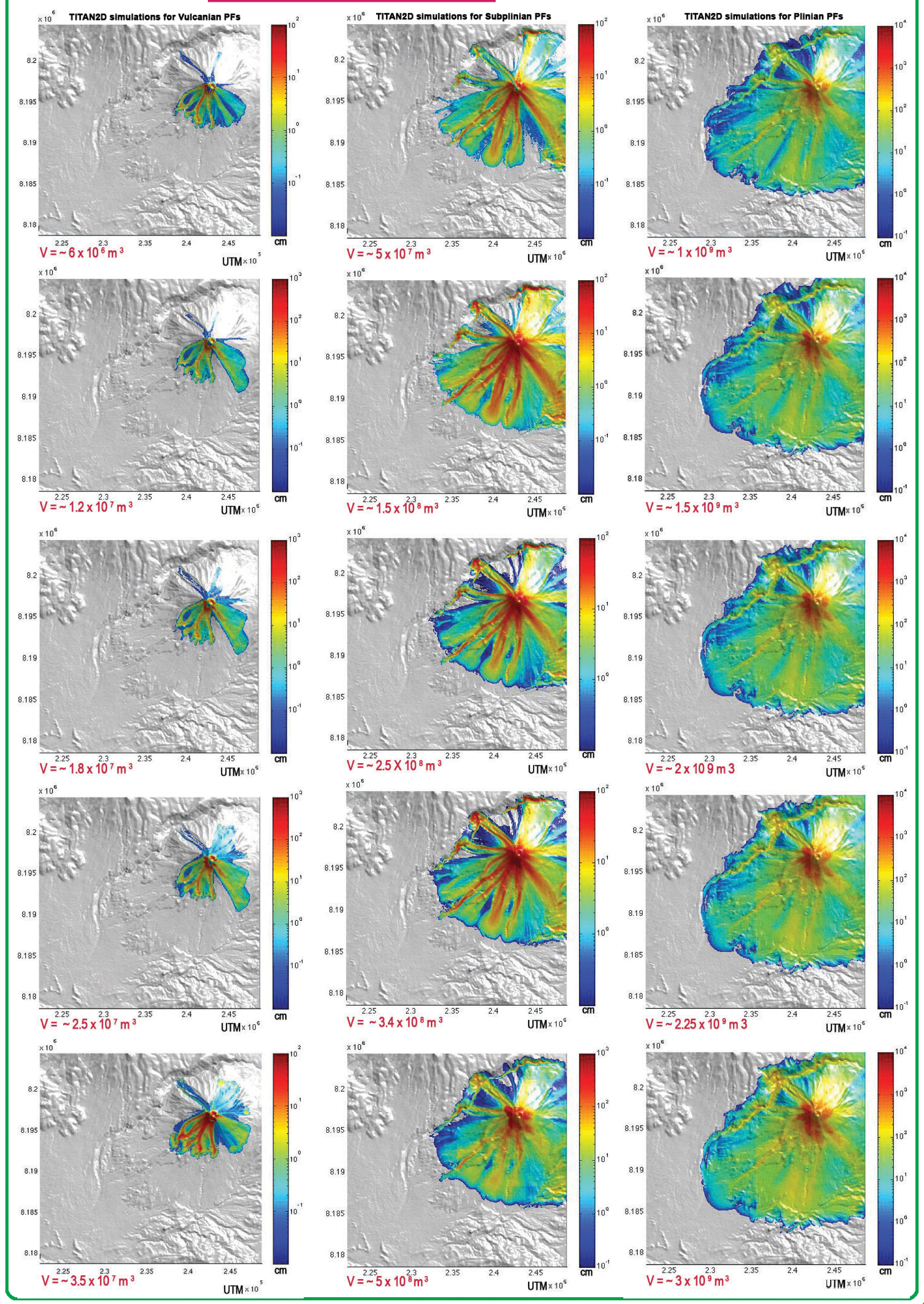


PFs deposits of the 2030 - 2050 B.C Subplinian - Plinian eruption



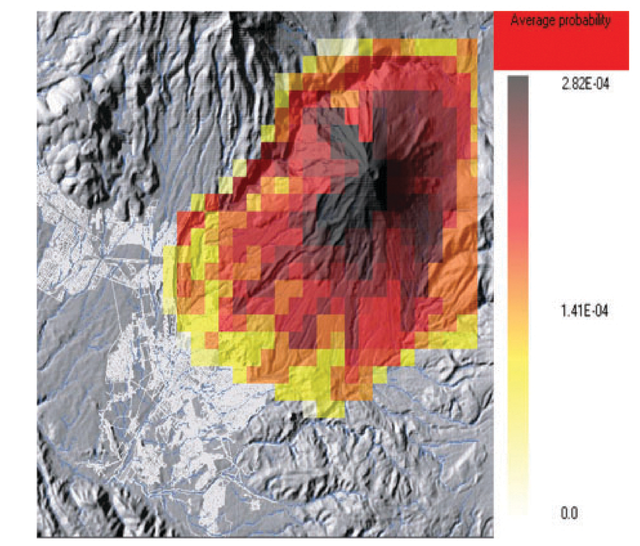
PFs deposits from the ~ 14.000 B.C., ~ 25.000 B.C. and ~34.000 B.C. Plinian eruptions

TITAN2D simulations as Prior Models

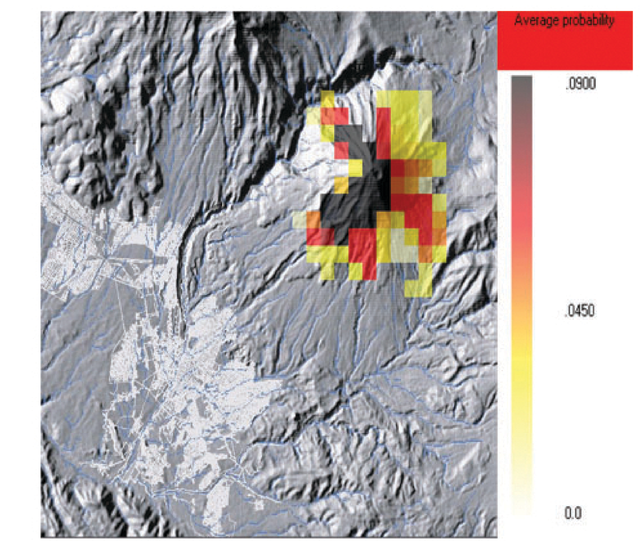


OUTPUT

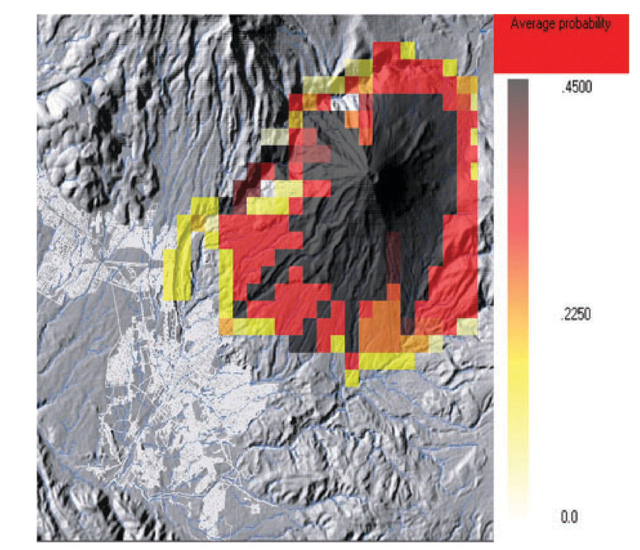
BET_VH PROBABILITY MAPS



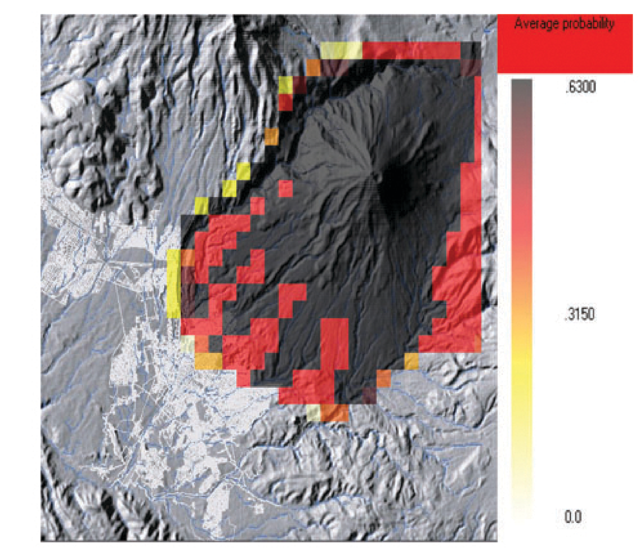
Absolute probability **map of a location to be reached by PFs generated by any type of the selected eruptions within 1 year**



Conditional probability **map of a location to be reached by PFs generated by a Vulcanian / Phreatomagmatic eruption**



Conditional probability **map of a location to be reached by PFs generated by a Subplinian eruption**



Conditional probability **map of a location to be reached by PFs generated by a Plinian eruption**

TITAN2D RESULTS

- the simulated *Vulcanian* flows, restricted to the upper part of the cone, become confined (0.1-1m thick) in the ravines which converge towards each of the three Quebradas.

- the *Subplinian* PF deposits reach 0.1 to 1 m thick in the Quebradas and 1-4 m WNW of El Misti summit in the Rio Chili canyon. The simulation runs suggest that the Subplinian flows will reach a 9 to 12 km distance, i.e. within the uppermost city suburbs on the W, SW and S flanks of El Misti.

- large *Plinian* events with volumes exceeding $10^9\ m^3$ produce simulated flows that would reach 15 km distance, i.e 3 km beyond the extent of existing similar deposits. On the steep NW flank of El Misti summit, the Subplinian and Plinian PFs run up 500-700 m on the opposite slope of the 2 km-wide canyon and bounce back to the channel to form deposits 1 to 7 m thick.

BET_VH results

The BET_VH results are illustrated through two maps:

(1)Conditional probability maps show the probability for PFs to reach a selected location given any of the selected eruption sizes. For example, the probability that PFs generated by a Plinian eruption to reach the city suburbs upstream of Qdas. Huarangal and San Lazaro is >0.6.

(2)Absolute probability maps provide the probability for different parts of the city to be reached by PFs within the next year.

CONCLUSIONS

The main goal of this assessment is to provide a probabilistic view over the PF hazard which has significant implications on the risk assessment. Given the Bayesian approach, the possibility to combine various sources of information is used, thus it is showed how individual separate models can be used and how they influence the distribution of probability.

Both field observations and numerical simulations show the similarities in terms of the extent of PFs deposits. BET_VH can assign probabilities to locations likely to be impacted by the phenomena. However BET is limited by the quality of the input data as the completness of the eruptive history of the volcano and the quality and number of the numerical simulations used as prior models.

BET_VH can offer an insight of what we may expect from a volcanic eruption long before it happens. The conditional and absolute probability maps are important assets for long-term hazard assessment. Having probabilities before an eruption, the decision – makers can take mitigation measures long before a crisis therefore decreasing the risk.

For Misti and Arequipa case study a more detailed research is necessary but the results presented here can stay as a landmark for any further research.

References

Marzocchi W, Sandri L, Selva J (2008) BET_EF: a probabilistic tool for long- and short-term eruption forecasting. Bull. Volc. 70:623–632

Marzocchi W, Sandri L, Selva J (2010) BET_VH: a probabilistic tool for long-term volcanic hazard assessment. Bull. Volc. 72: 705 - 716

Murcia H.F, Sheridan M.F, Macias J.L, Cortes G.P (2010) TITAN2D simulations of pyroclastic flows at Cerro Machin Volcano, Colombia: Hazard implications. J. South Amer. Eart. Scien. 29: 161 – 170

Procter J.N, Cronin S.J, Platz T, Patra A, Dalbey K, Sheridan M.F, Neall Vince (2010) Mapping block-and-ash flow hazard based on Titan 2D simulations: a case study from Mt. Taranaki, NZ. Nat. Hazards 53: 483 – 501

Sheridan M.F, Stinton A.J, Patra A, Pitman E.B, Bauer A, Nichita C.C (2005) Evaluating Titan2D mass – flow model using the 1963 Little Tahoma Peak avalanches, Mount Rainier, Washington. J. Volc. Geoth. Research 139: 89 – 102

Thouret, J.-C, Finizola A, Fornari M, Legeley-Padovani A, Frechen M., (2001) Geology of El Misti volcano near the city of Arequipa, Peru: Geol. Soc. Ame. Bull. 113/12, p. 1593–1610.

Thouret, J.-C., Suni, J., Eissen, J-Ph., Navarro, P. (1999b) Assessment of volcanic hazards in the Arequipa area bases on the eruptive history of Misti volcano, southern Peru. Zeitschift für Geomorphologie 114: 89-112.

Vargas R.F, Thouret J,C, van Westen C, Sheridan M.F, Siebe C, Marino J, Souriot T, Stinton A (2010) Mapping and assessing volcanic and flood hazards and risks with emphasis on lahars, in Arequipa, Peru. Geol.Soc.Amer. Special Paper 464: 265 - 280