AIV
Associazione Italiana di Vulcanologia

ISTITUTO NAZIONALE
DI GEOFISICA E VULCANOLOGIA

UNIVERSITÀ
degli STUDI
di CATANIA

CONFERENZA A. RITTMANN

Eruption forecasting and hazard assessment at INGV during the 2019 crisis exercise at Campi Flegrei

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CATANIA 12|14 Febbraio 2020

Con il patrocinio di

IAVCEI

Simulation ExeFlegrei in 2019

- 16-19 October 2019
- It was organized by National Civil Protection (DPC) and it involved DPC, DPC components (among them there is INGV) and population
- A group of experts simulated an anomalous behavior at Campi Flegrei, across **4 phases** (each pretending to last several months/weeks), **providing for each phase general information** (e.g., how many events in a seismic swarm without date, max magnitude, max uplift…):

1) 2years – 6months before eruption: Mmax, LPs, few VTs

2) 6months – 2months before eruption: Mmax, LPs, VTs, *Uplift, Increased gas fluxes, Phreatic explosions*

3) 2months-2weeks before eruption: Mmax, LPs, VTs, Uplift, Increased gas fluxes, Phreatic explosions, *Acid Gases detected, Deviation from bell-shaped deformation pattern, New fractures, New hydrothermal sources*

4) 2weeks before eruption: Mmax, LPs, VTs, Uplift, Increased gas fluxes, Phreatic explosions, Acid Gases detected, Deviation from bell-shaped deformation pattern, New fractures, New hydrothermal sources, *Tremor*

INGV response during ExeFlegrei:

1) Eruption forecasting

2) Scenario forecasting: vent position

3) Hazard assessment I: tephra ground loading

4) Hazard Assessment II: PDC invasion

5) ... Lessons learned?

INGV response during ExeFlegrei:

1) Eruption forecasting

2) Scenario forecasting: vent position

3) Hazard assessment I: tephra ground loading

4) Hazard Assessment II: PDC invasion

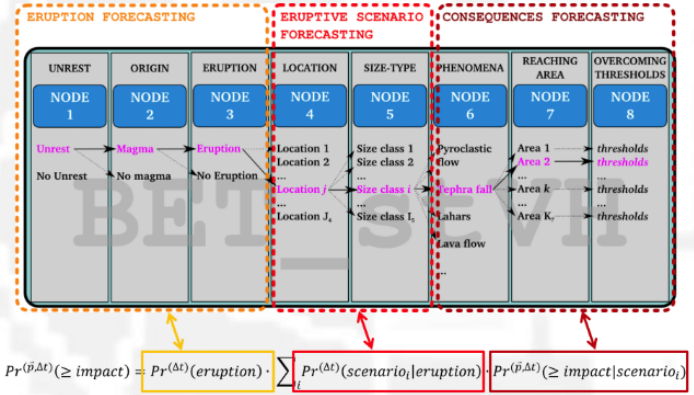
5) ... Lessons learned?

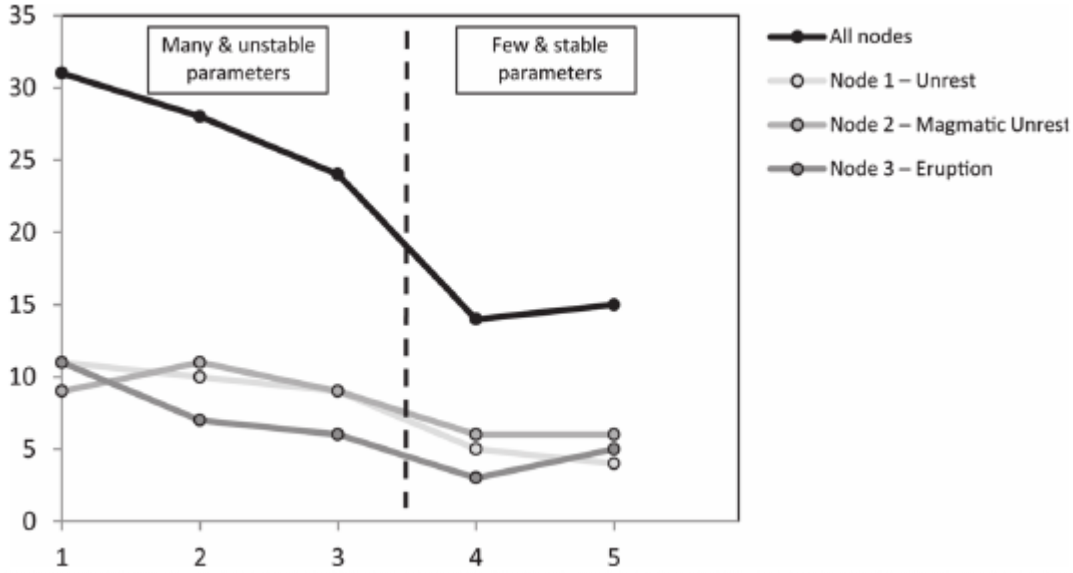
Report on the “State of the volcano”

Report on the “Hazard Assessment”

State of the volcano – Eruption forecasting

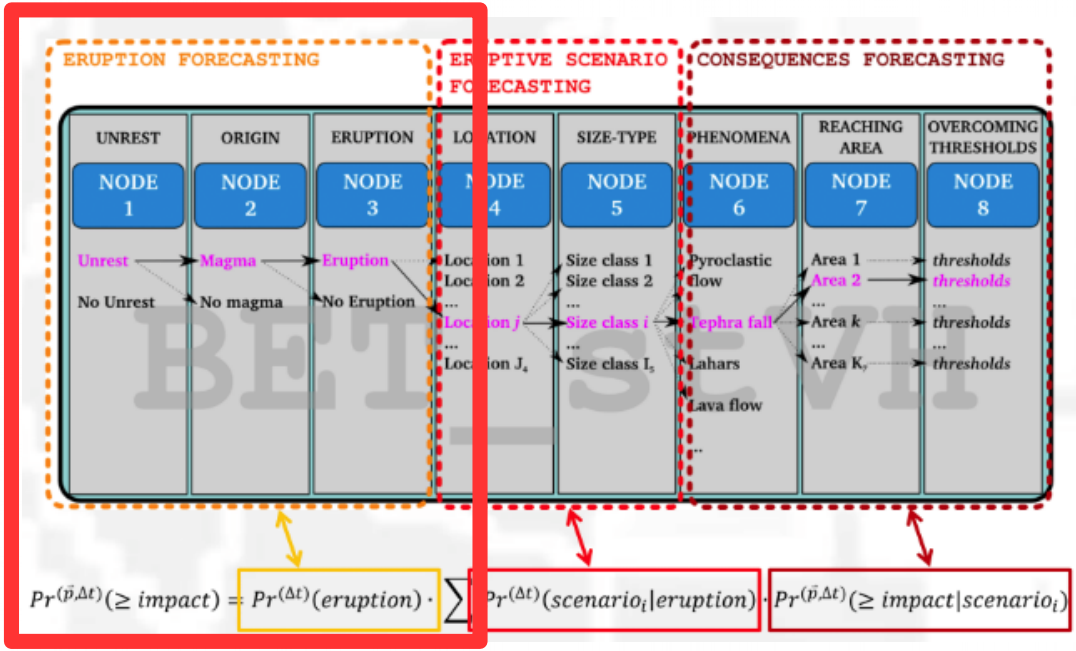
Last elicitation in project B2 DPC-INGV 2015

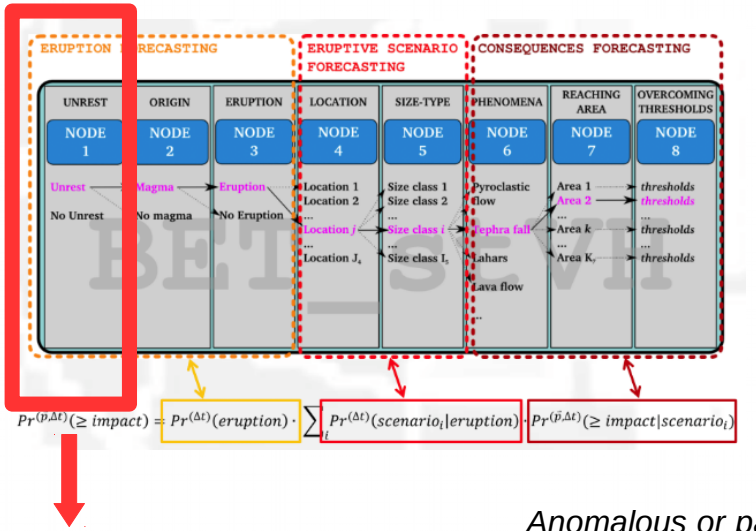




Evaluation of the state of the volcano - Update for 18 Oct, 2019 (morning) slide 1/4

Next month probability based on BET calibrated on the resiults from last elicitation experiment (project B2 DPC-INGV 2015)



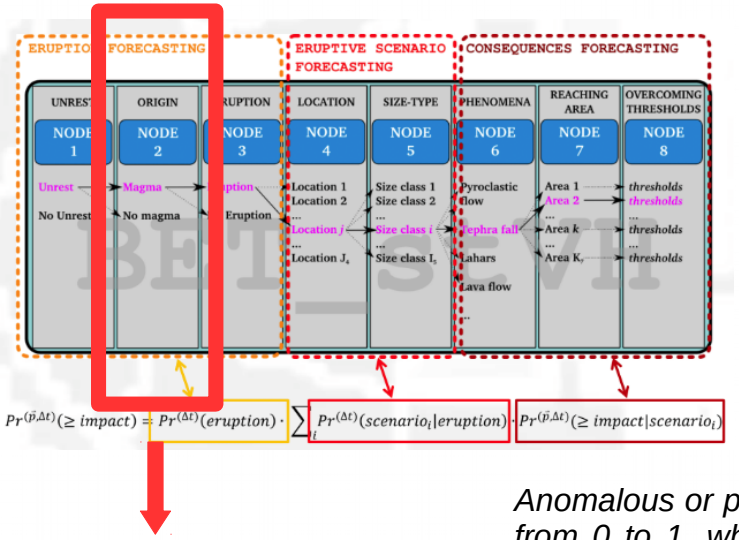


Prob. unrest
Mean: 1.0
10th Perc 1.0
50th Perc 1.0
90th Perc 1.0

Anomalous or partially anomalous parameters (parameters' "degree of anomaly", from 0 to 1, where 0 stands for "PARAMETER NOT ANOMALOUS" and 1 for "PARAMETER COMPLETELY ANOMALOUS"):

Max Magnitude (degree of anomaly: **1**)
Number of LP/VLP/ULP (degree of anomaly: **1**)
Number of VT (degree of anomaly: **1**)
3-month accumulated uplift (degree of anomaly: **1**)
Extension in degassing structures or increase in fluxes (degree of anomaly: **1**)
Uplift rate(degree of anomaly: **1**)
Presence of acid gases (degree of anomaly: **1**)

Evidenziate in giallo le anomalie la cui posizione viene usata per aggiornare la mappa di apertura di bocche con il metodo 2 (Selva et al)

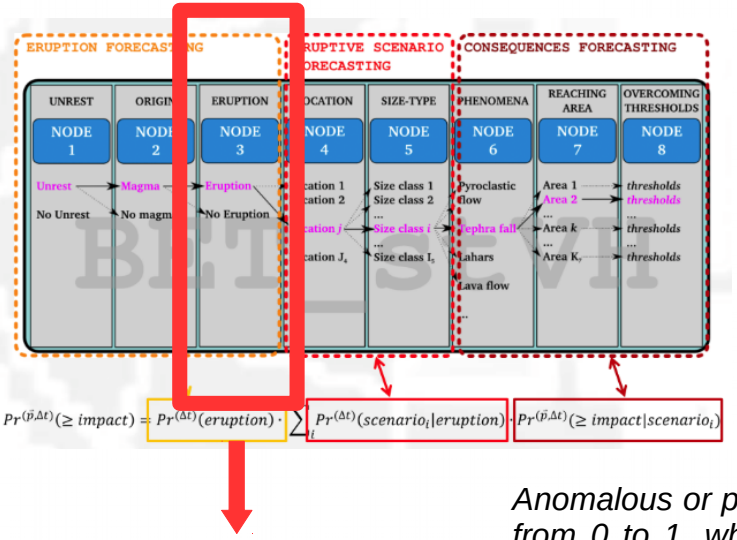


Prob magmatic unrest
Mean: 0.93
10th Perc 0.76
50th Perc 1.0
90th Perc 1.0

Anomalous or partially anomalous parameters (parameters' "degree of anomaly", from 0 to 1, where 0 stands for "PARAMETER NOT ANOMALOUS" and 1 for "PARAMETER COMPLETELY ANOMALOUS"):

Max Magnitude (degree of anomaly: **1**)
Number of LP/VLP/ULP (degree of anomaly: **1**)
Number of VT (degree of anomaly: **1**)
3-month accumulated uplift (degree of anomaly: **0.05**)
Extension in degassing structures or increase in fluxes (degree of anomaly: **1**)
Significant variazioni in Vhor/Vup at any GPS station (degree of anomaly: **1**)
Uplift rate(degree of anomaly: **1**)
Presence of acid gases (degree of anomaly: **1**)

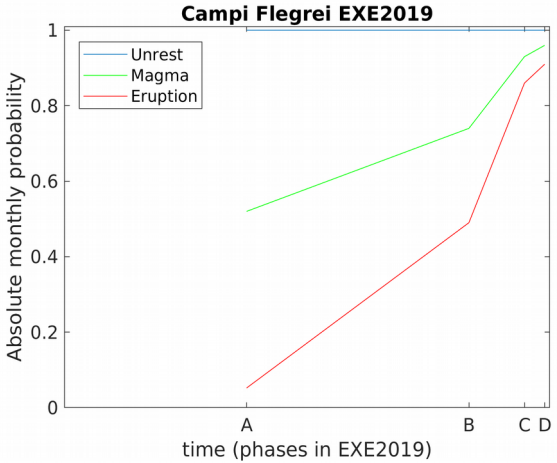
Evidenziate in giallo le anomalie la cui posizione viene usata per aggiornare la mappa di apertura di bocche con il metodo 2 (Selva et al)

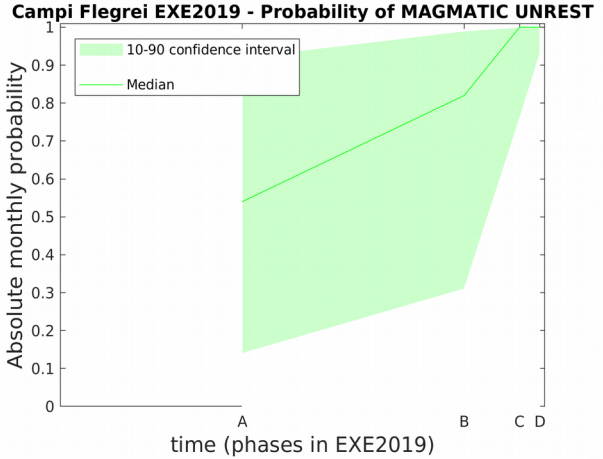


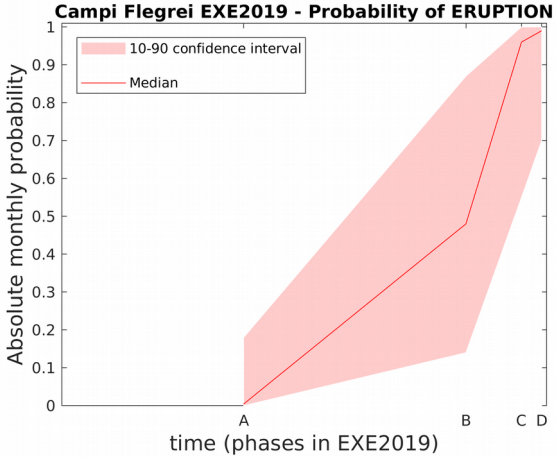
Prob magmatic eruption
Mean: 0.86
10th Perc 0.55
50th Perc 0.96
90th Perc 1.0

Anomalous or partially anomalous parameters (parameters' "degree of anomaly", from 0 to 1, where 0 stands for "PARAMETER NOT ANOMALOUS" and 1 for "PARAMETER COMPLETELY ANOMALOUS"):

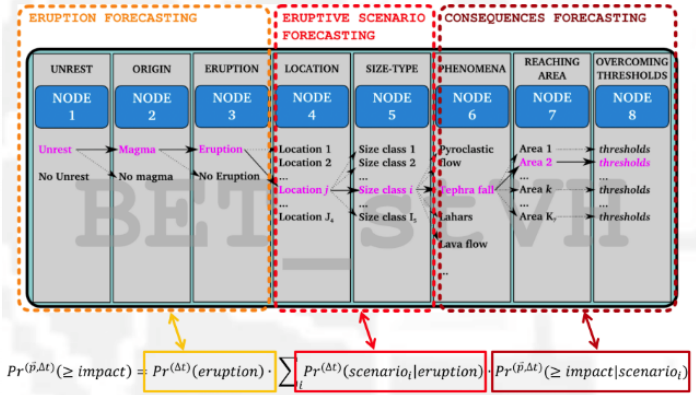
Phreatic explosions (degree of anomaly: **1**)
New fracture opening (degree of anomaly: **1**)
Significant variazioni in Vhor/Vup at any GPS station (degree of anomaly: **1**)
Presence of acid gases (degree of anomaly: **1**)
New hyfrothermal sources (degree of anomaly: **1**)


Campi Flegrei EXE2019
Unrest
Magma
Eruption
Absolute monthly probability
time (phases in EXE2019)
A
B
C D


Campi Flegrei EXE2019 - Probability of MAGMATIC UNREST
10-90 confidence interval
Median
Absolute monthly probability
time (phases in EXE2019)
A
B
C D


Campi Flegrei EXE2019 - Probability of ERUPTION
10-90 confidence interval
Median
Absolute monthly probability
time (phases in EXE2019)
A
B
C D

State of the volcano – Scenario forecasting



Vent Position

Two different doubly stochastic models (Selva et al, 2012, Bevilacqua et al, 2019):
- both the resulting maps were described by a *best-evaluation* map displaying the aleatory uncertainty, and *percentile maps* to quantify the epistemic uncertainty
- both contained the long-term information from Campi Flegrei morphological and geological history, and implemented a mechanism to assimilate the information from the monitoring data given in the bulletin at t_0

Eruptive Size

Tephra fallout: from Orsi et al (2009)

Conditional probability for the four different eruptive sizes at Campi Flegrei, updated from Orsi et al. (2009).

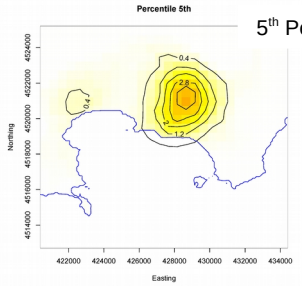
Size class	Mean	Median	16th percentile	84th percentile
Effusive	11.0	10.2	5.5	16.6
Size Small explosive	62.6	62.9	53.7	71.6
Size Medium explosive	22.5	21.9	14.8	30.0
Size Large explosive	3.9	2.9	0.8	6.9

PDC invasion: no explicit assumption on eruptive size, as the PDC-invaded area is taken from field record

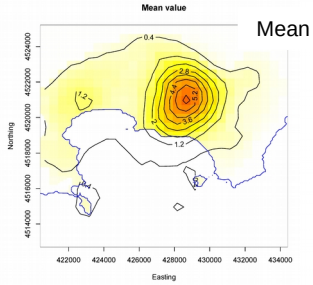
Vent Position: epistemic uncertainty

*Example for **Phase D***

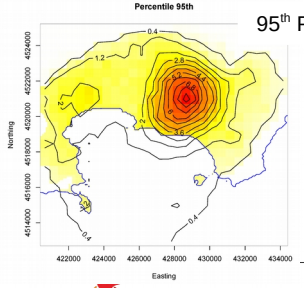
Selva et al (2012) method (used also in 2014)



5th Percentile

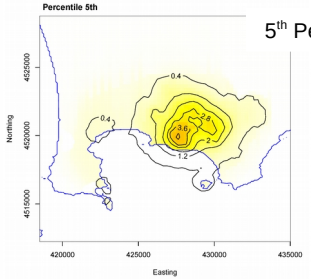


Mean

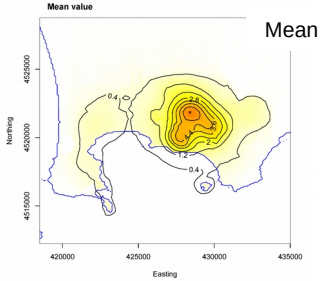


95th Percentile

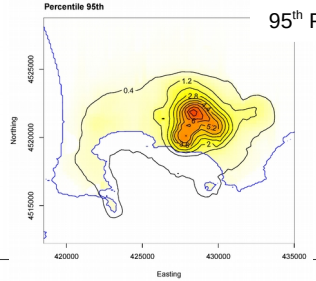
Bevilacqua et al (2019)



5th Percentile

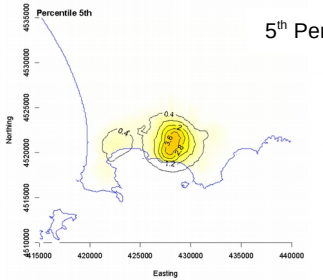


Mean

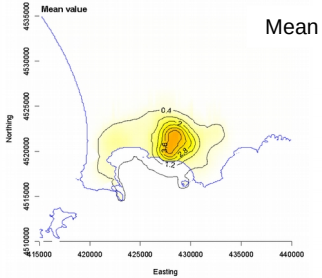


95th Percentile

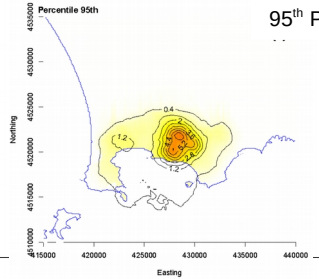
Ensemble of the two



5th Percentile

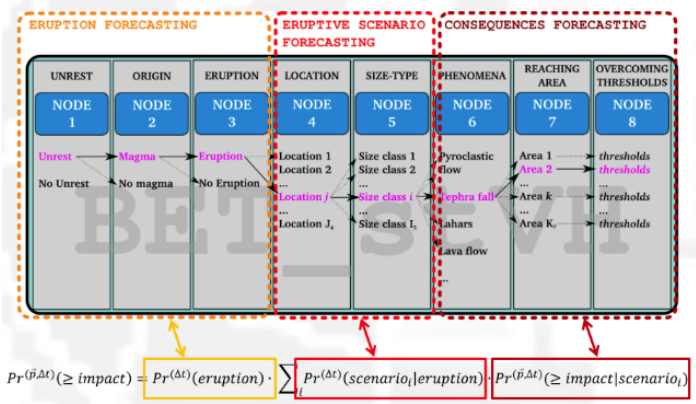


Mean



95th Percentile

Hazard assessment



Tephra fallout

- tephra load accumulated on the ground in 24 hours given an eruption starting at t_0, t_0+24h and t_0+48h
- hazard curves, doubly stochastic, conditional to the occurrence of an *explosive eruption*
- hazard curves, doubly stochastic, conditional to the occurrence of an *eruption of a specific size* (so-called Small, Medium and Large explosive scales)
- obtained by combining specific simulations of tephra fallout based on Small, Medium and Large explosive scenarios obtained using the Fall3D model (Folch et al, 2009) run with the most recent available weather forecast at the time of the bulletin
- both maps for vent opening separately, and the ensemble

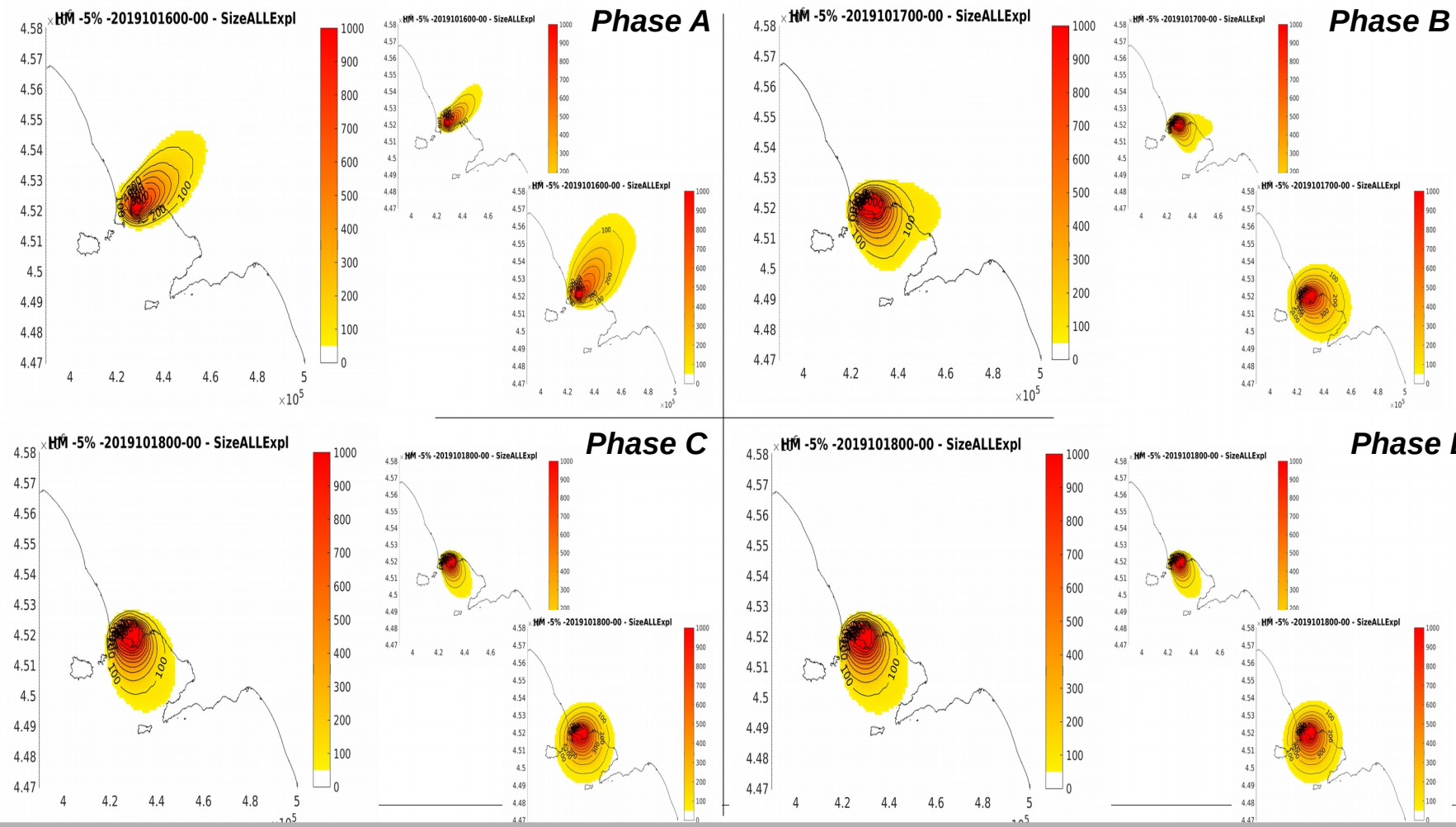
Tephra fallout hazard assessment:

- Hazard maps or Probability maps? Thresholds?

- What eruption size? Any size? Any explosive size? A specific size?

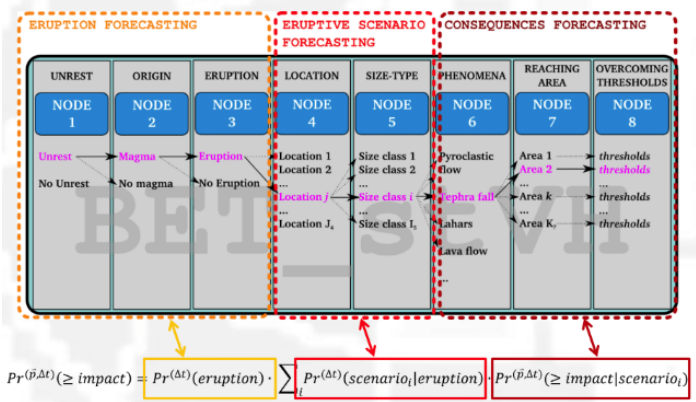
- What time window is of interest?
[t_0, t_0+24h] or [t_0+24, t_0+48h] or [t_0+48, t_0+72h]

- What vent map? The ensemble?



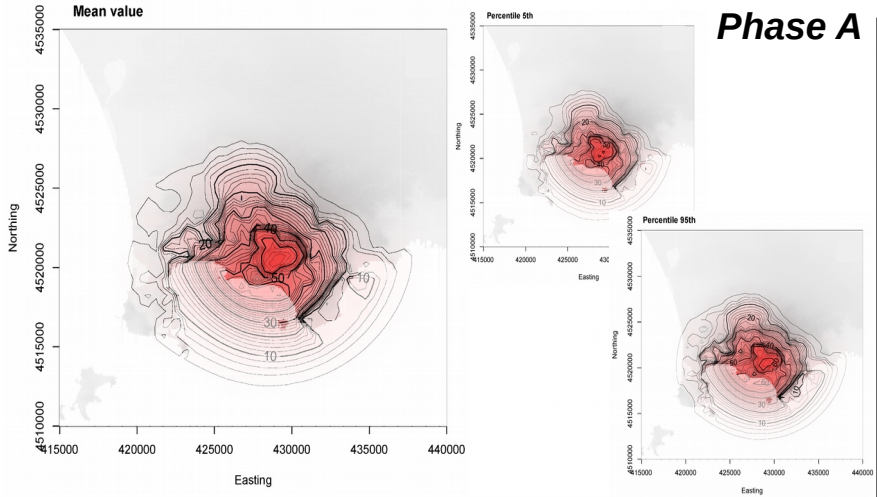
Example: Hazard map at 5%, [t_0, t_0+24h], any explosive size, ensemble vent map

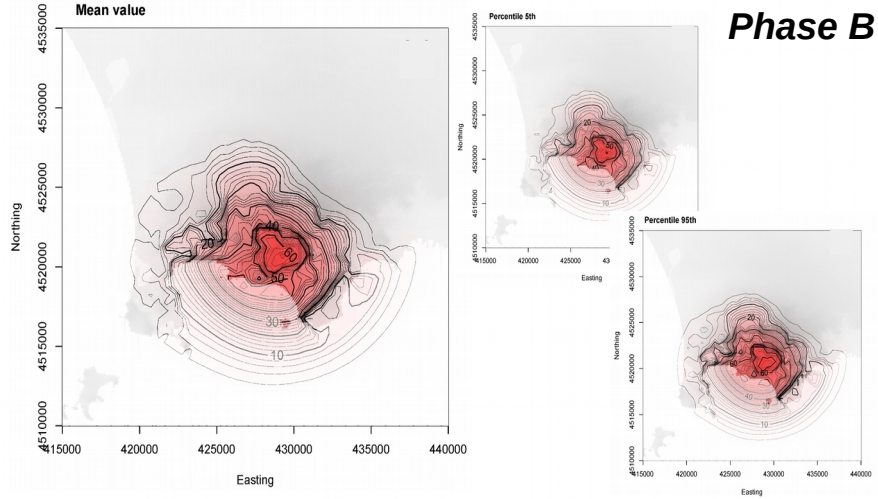
Hazard assessment

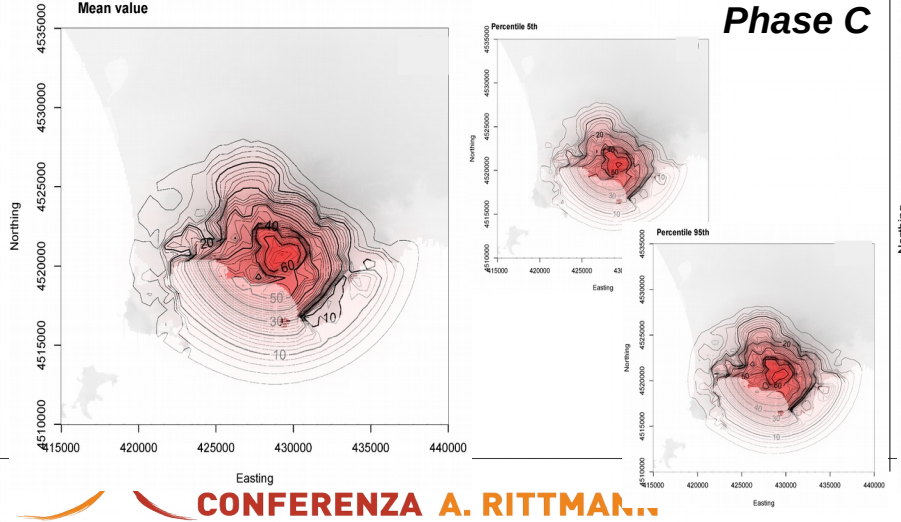


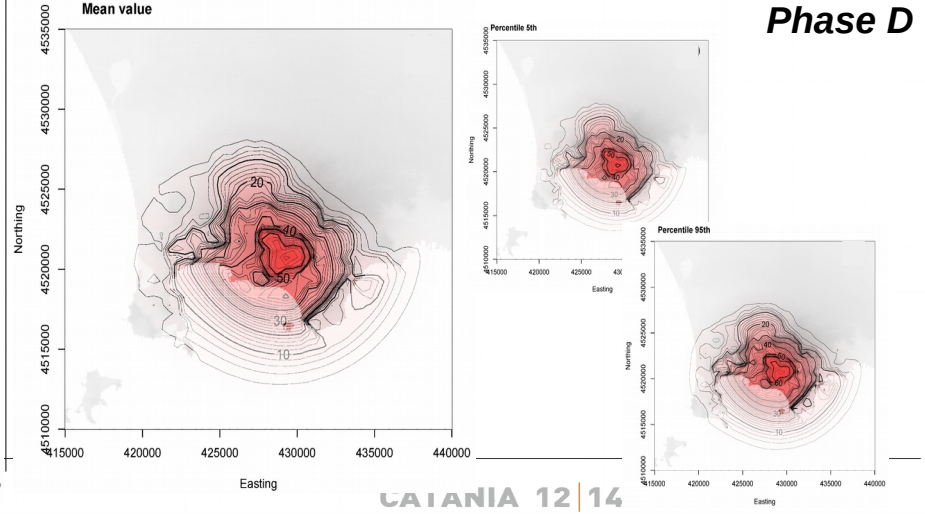
PDC invasion

- doubly stochastic maps of the probability of PDC invasion, conditional to the occurrence of an *explosive eruption*
- obtained by a simplified kinematic model called “box model” that propagates the PDC (Neri et al., 2015)
- the size of PDCs was based on a lognormal statistics of inundated regions by past PDCs, and included the main uncertainty sources affecting the deposit extent and a number of not measured but recognized small-sized PDC in the record
- the PDC size was also correlated to the caldera sector on which the PDC originated
- both maps for vent opening separately, and the ensemble


Mean value
Percentile 5th
Percentile 95th
Phase A
Northing
Easting


Mean value
Percentile 5th
Percentile 95th
Phase B
Northing
Easting


Mean value
Percentile 5th
Percentile 95th
Phase C
Northing
Easting


Mean value
Percentile 5th
Percentile 95th
Phase D
Northing
Easting

1- Good news

- DPC expressed specific interest on "pre-eruptive" products, i.e., unrest and eruption probability, and spatial probability maps for the vent position. Not much attention was paid to hazard and probability maps for tephra ground accumulation and PDC invasion (Exe Flegrei terminated before the eruption oset)

- The probabilistic nature of our results was an effective way to communicate our knowledge and ignorance.

2- Criticalities

- short time between subsequent phases of the simulation and high computational cost requested for the mapping
→ not possible to propagate in real-time the epistemic uncertainty on the position of the vent and on the eruption size to the hazard and probability maps for tephra load (only the mean maps were produced in real time)

- the number of maps resulting from hazard assessment can grow very (too) rapidly:
- multiple threshold values in probability or intensity measure (e.g., tephra load)
- combinations of possible scenarios (size and vents)
- hazards (e.g., tephra fallout and PDCs in this case)
- percentiles to better quantify epistemic uncertainty
- different forecasting time windows (i.e.,t_0, t_0+24h and so on, in the case of tephra fallout).

→ This can make the communication with decision makers very difficult and the results not fully exploitable

Lessons learned

- the models used to provide these assessments should be constantly upgraded as new scientific knowledge is gained, and translated in advance into formalized operational procedures

- the exploitation of the large portfolio of existing hazard products needs a continuous cooperation between scientists and decision makers. This is indeed a necessarily ***mutual exchange process***

- periodic crisis exercises represent fundamental opportunities to improve the response of the scientific and civil protection communities to major volcanic emergencies

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- periodic crisis exercises represent fundamental opportunities to improve the response of the scientific and civil protection communities to major volcanic emergencies

Grazie!!!

Lessons learned

- the models used to provide these assessments should be constantly upgraded as new scientific knowledge is gained, and translated in advance into formalized operational procedures

- the exploitation of the large portfolio of existing hazard products needs a continuous cooperation between scientists and decision makers. This is indeed a necessarily mutual exchange process: on the one hand, in peace times the decision makers' needs should become clearer to scientists. Scientist and decision makers could conceive priority levels (e.g., defining high, medium and low priority) for the products that may go in reports to decision makers and in internal reports. On the other hand, scientists should struggle to better communicate the amount and quality of information carried in their study and products
- periodic crisis exercises represent fundamental opportunities in order to improve the response of the scientific and civil protection communities to major volcanic emergencies.

Vent Position: best-evaluation maps

NEW

Selva et al (2012) method (used also in 2014)

Bevilacqua et al (2019)

Ensemble of the two