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

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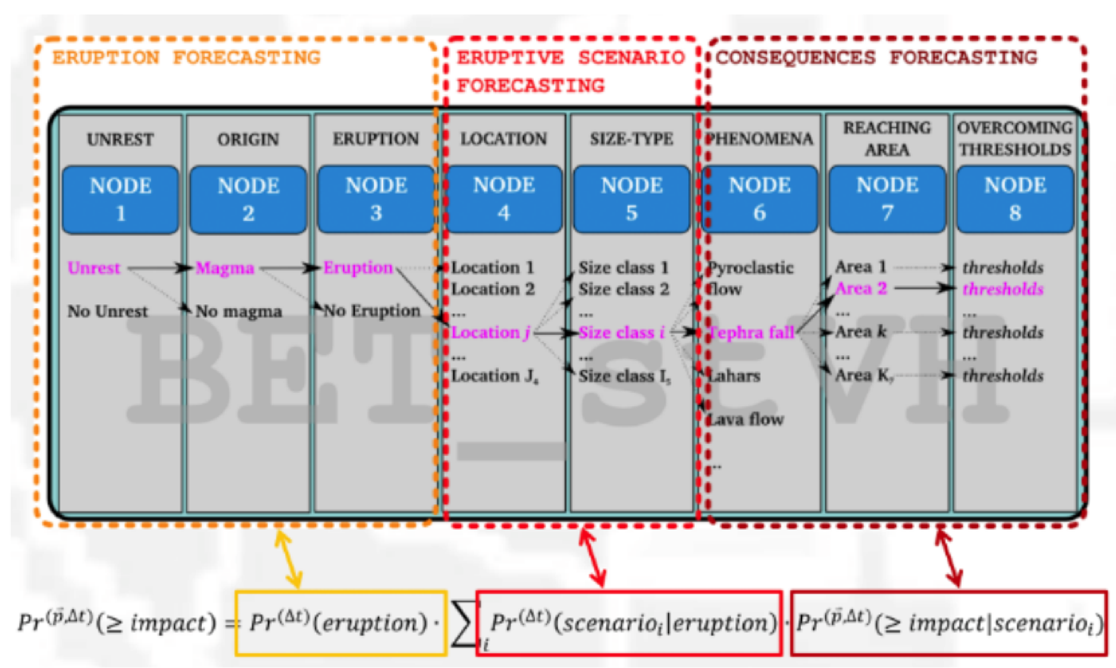
Abstract

From 16 to 19 October 2019, the Italian Civil Protection (DPC) organized a crisis exercise at Campi Flegrei, called **ExeFlegrei 2019**, to verify internal procedures and communication flows towards/from institutions and towards population. At INGV the exercise allowed to verify monitoring communication workflows and to test and upgrade operational procedures for real-time eruption forecasting and hazard assessment.

As regards the latter aspects, following the evolution of the volcanic activity as resulted from the issued bulletins at each time t_0, the INGV team provided:

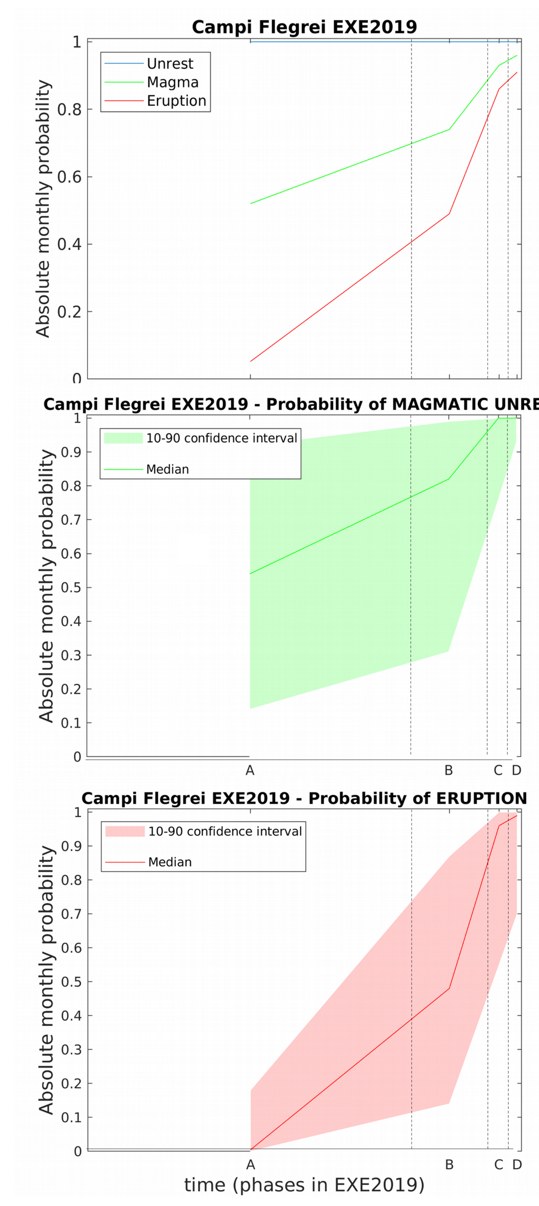
- in terms of *eruption forecasting*, real-time probabilities (with 80% confidence interval) for unrest, magmatic unrest, and eruption in the month following t_0, based on the BET_EF model (Marzocchi et al, 2008) calibrated during a long series of past elicitation experiments (Selva et al, 2012a)
- in terms of *scenario forecasting*, real-time spatial probability maps for vent opening according to two different models (Selva et al, 2012b; Bevilacqua et al, 2015), conditional on the occurrence of an eruption
- in terms of *hazard assessment*, real-time hazard and probability maps for **tephra load** accumulated at the ground, and real-time probability maps for the **invasion of pyroclastic density currents** (PDCs), all conditional to the occurrence of an eruption.



$$Pr^{(\Delta t)}(\geq impact) = Pr^{(\Delta t)}(eruption) \cdot \sum Pr^{(\Delta t)}(scenario_i|eruption) \cdot Pr^{(\Delta t)}(\geq impact|scenario_i)$$

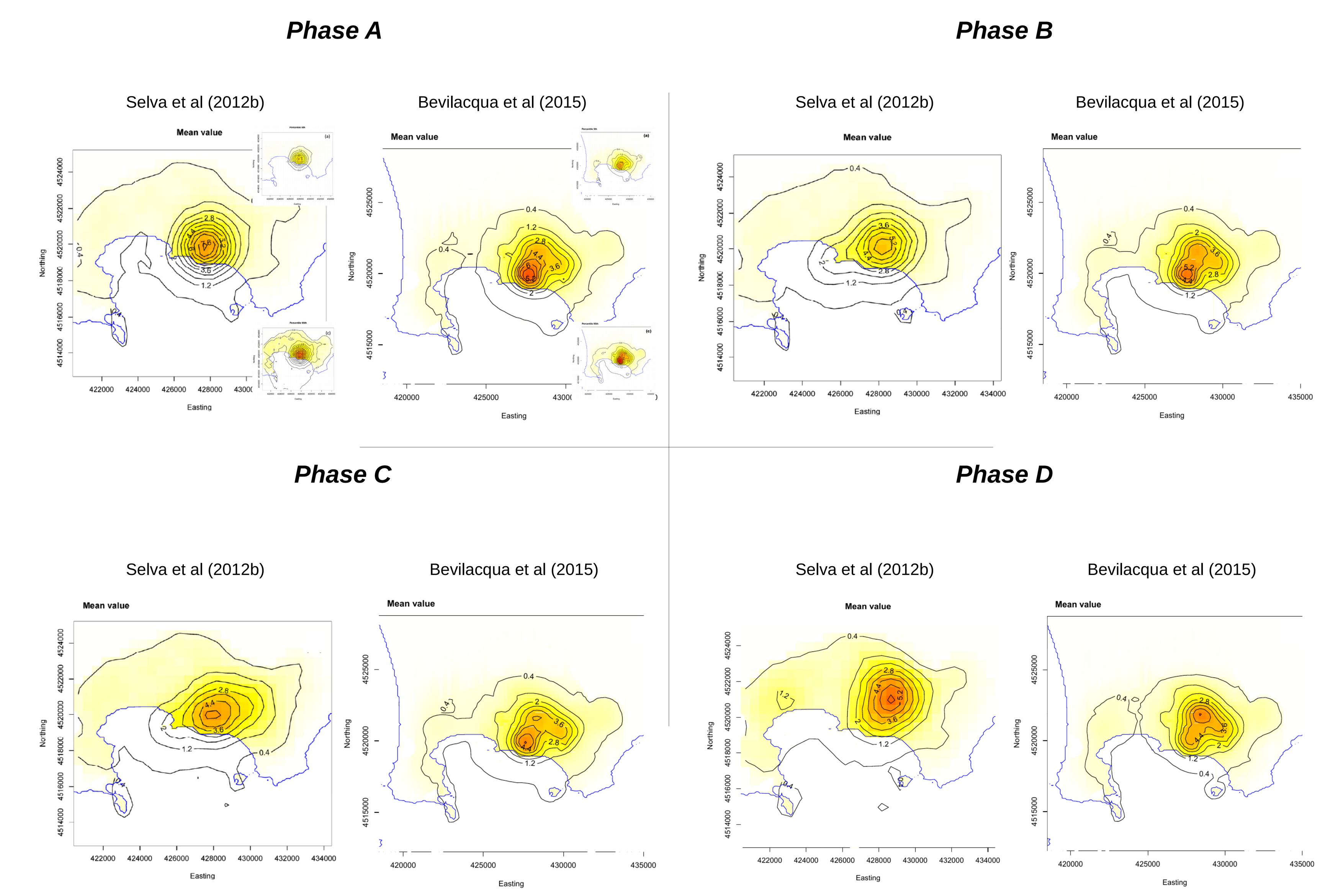
Eruption forecasting

Based on the method by Selva et al (2012a) and on a ca. 10-year long process of elicitation sessions, stopped in 2015. Monitoring data from bulletins, if anomalous, were included in the forecast at the different phases.



Scenario forecasting: vent opening map

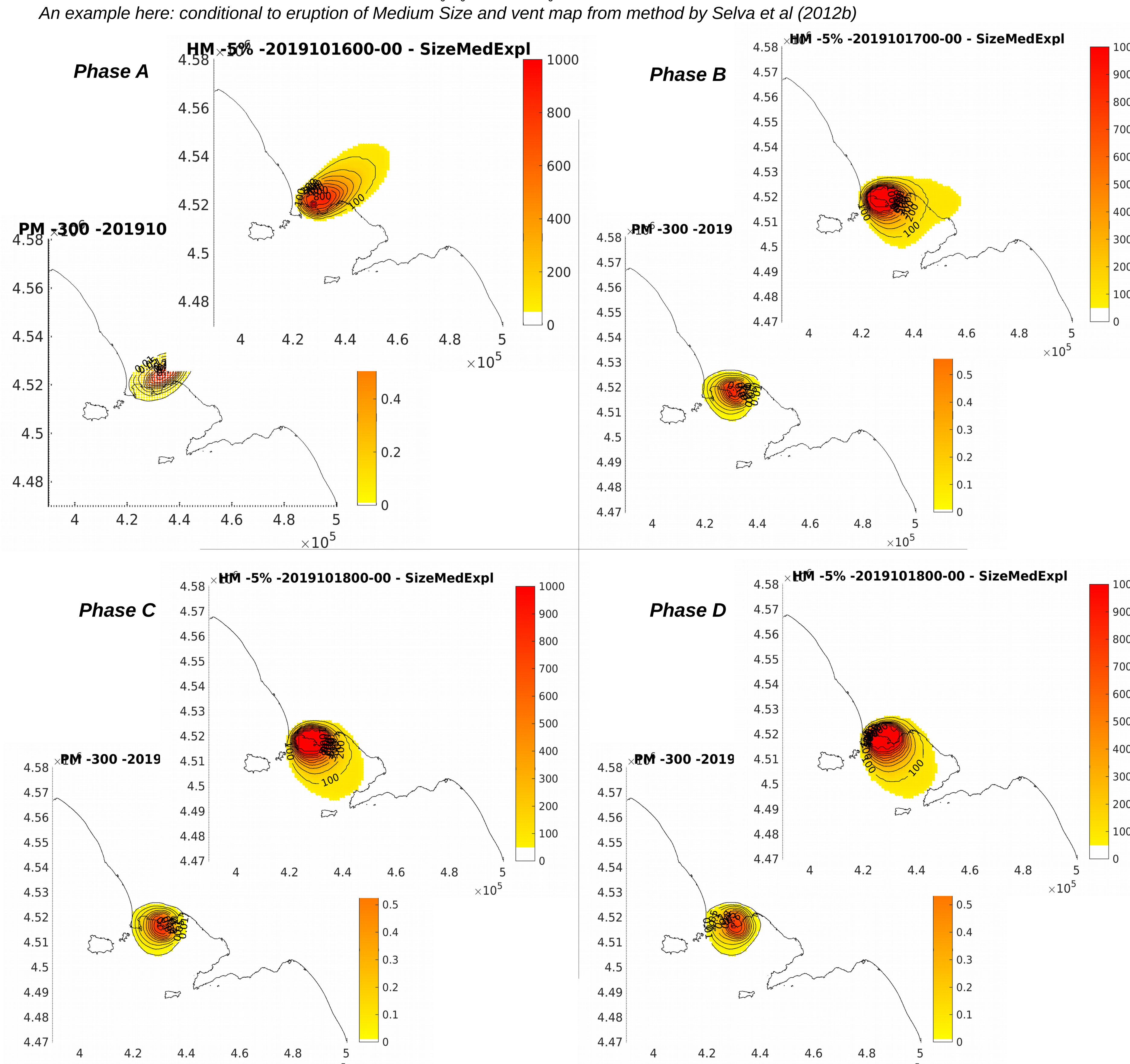
We used two different models following a Bayesian, or doubly stochastic, approach: both the resulting maps were described by a best-evaluation map displaying the aleatory uncertainty, and percentile maps to quantify the epistemic uncertainty. Also, they both contained the long-term information from Campi Flegrei morphological and geological history, and implemented a mechanism to assimilate the information from the monitoring data given in the bulletin at t_0



Hazard assessment: tephra fallout

We computed hazard curves conditional to the occurrence of an explosive eruption and conditional to the occurrence of an eruption of a specific size (so-called Small, Medium and Large explosive scales), as by Orsi et al (2009). The hazard curves can be cut to achieve hazard/probability maps, which were produced for different threshold in exceedance probability/load, and were 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) combined with the most recent available weather forecast at the time of the bulletin. We simulated the tephra load accumulated on the ground in 24 hours given an eruption starting at t_0, t_0+24h and t_0+48h. We made use of both maps for vent opening separately.

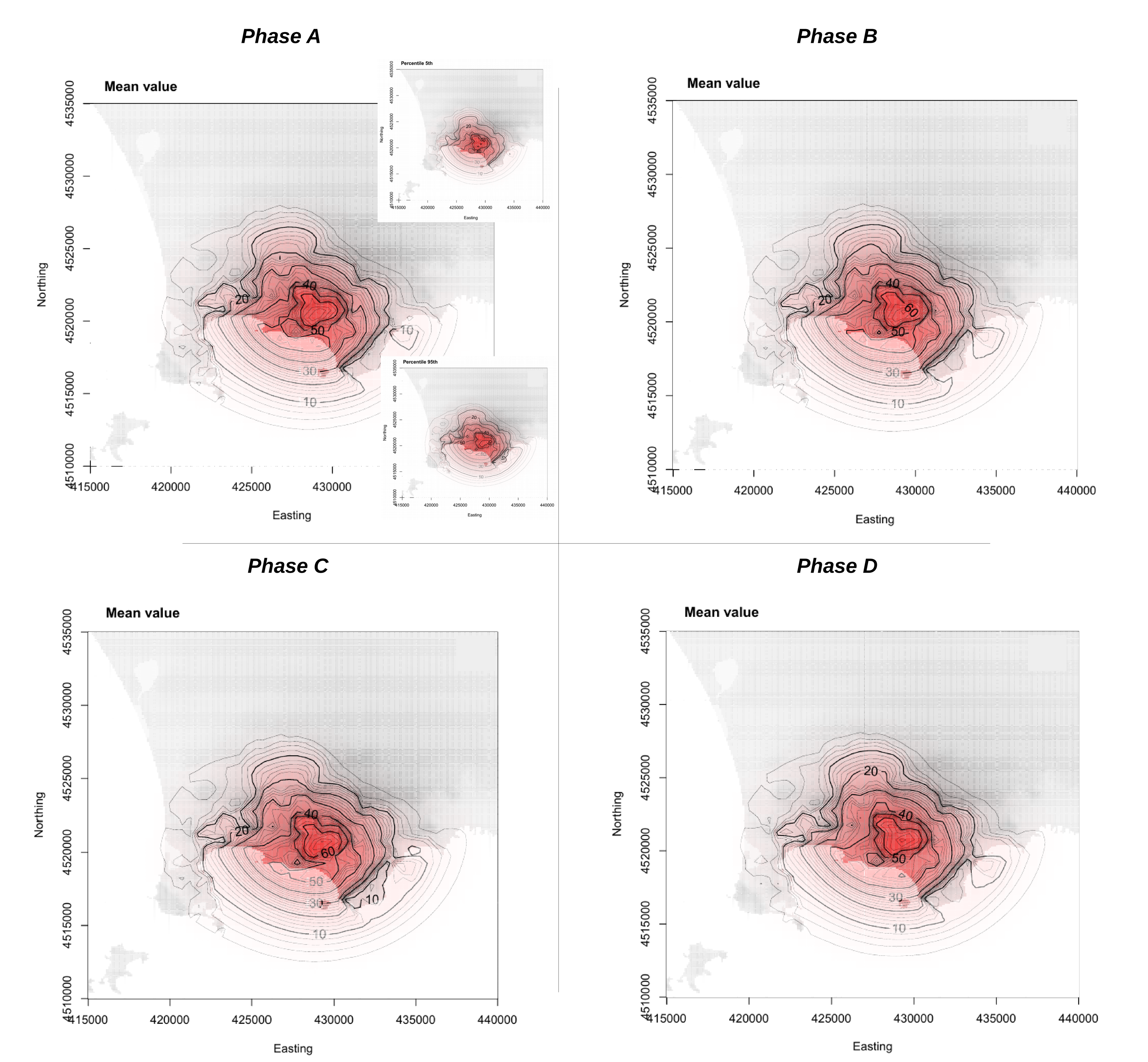
An example here: conditional to eruption of Medium Size and vent map from method by Selva et al (2012b)



Hazard assessment: PDC invasion

We computed maps of the probability of PDC invasion based on the vent opening maps produced in real-time, and a simplified kinematic model called "box model" that propagates the PDC (Neri et al., 2015). The size of the PDC 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 (Bevilacqua et al., 2017).

An example here: conditional to eruption of any size and vent map from method by Bevilacqua et al (2015)



EXE Campi Flegrei 2019 and VOBP4: lessons learned?

1- Which of your actions have been key to successes in your crisis responses (or simulations)?

In the course of the exercise, DPC expressed specific interest on "pre-eruptive" products, i.e., unrest and eruption probability, and spatial probability maps for the vent position. The probabilistic nature of our results was an effective way to communicate our knowledge and ignorance. On the other hand, not much attention was paid to hazard and probability maps for tephra ground accumulation and PDC invasion. This major interest in the pre-eruptive products was also motivated by the fact Exe Flegrei terminated before the eruption, when the Red Alert level, i.e. "imminent eruption", was enforced.

2- Were there any actions that you forgot/ now wish you had taken and what would you do differently, now that you can look back at your actions?

On our side, the main criticality arisen in our procedures during the exercise was that, due to the short time between subsequent stages of the simulation and to the high computational cost requested for the mapping, it was 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: indeed, only the mean maps were produced, quantifying the aleatory uncertainty only.

From a practical point of view, we also realized that the number of maps resulting from hazard assessment can grow very rapidly as consequence of the fact that we need to consider:
- multiple threshold values in probability or intensity measure (e.g., tephra load)
- combinations of possible scenarios (e.g., maps conditional to the occurrence of an eruption of any size, or of a specific sizes, or from the most likely vent position)
- hazards (e.g., tephra fallout and PDCs in this case), and maps considering the variability in vent opening
- 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 in the typical short time of the exercise.

3- If you were to choose just 3 lessons you'd like the rest of us to take home and consider as the basis for best-practice recommendations, what would they be?

- given the relevance for the decision makers of the eruption and scenario forecast, 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, which we believe represents a valuable and quantitative information for taking rational decisions during a volcanic crisis in a complex setting such as Campi Flegrei, needs a continuous cooperation between scientists and decision makers. This is indeed a necessarily mutual exchange process: on the one hand, the decision makers' needs should become clearer to scientists; 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.

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