Mapping long-term vent opening in a caldera setting with uncertainty estimation: application to Campi Flegrei caldera (Italy)

A. Bevilacqua[1,2], R. Isaia[3], A. Bertagnini[2], M. Bisson[2], C. Fourmentraux[2], F. Flandoli[4], E. Iannuzzi[5], A. Neri[2], M. Rosi[5], C. Scirocco[6], S. Vitale[6], W. P. Aspinall[7]

(1) Scuola Normale Superiore, Pisa
(2) Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Pisa, Pisa
(3) Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Vesuviano, Napoli
(4) Università di Pisa, Dip.to di Matematica Applicata, Pisa
(5) Università di Pisa, Dip.to di Scienze della Terra, Pisa
(6) Università di Napoli Federico II, Dip.to di Scienze della Terra, dell'Ambiente e delle Risorse, Napoli
(7) Dept. of Earth Sciences, University of Bristol, and Aspinall & Associates, Tisbury

**IAVCEI General Assembly 2013
Kagoshima, 20-24 July 2013**

INGV

SCUOLA NORMALE SUPERIORE PISA

UNIVERSITÀ DI PISA

Outline of the presentation

- The Campi Flegrei caldera

- The research objective

- The methodology used to produce the vent opening map

- New field data related to the reconstruction of past vent locations and distribution of faults and fractures

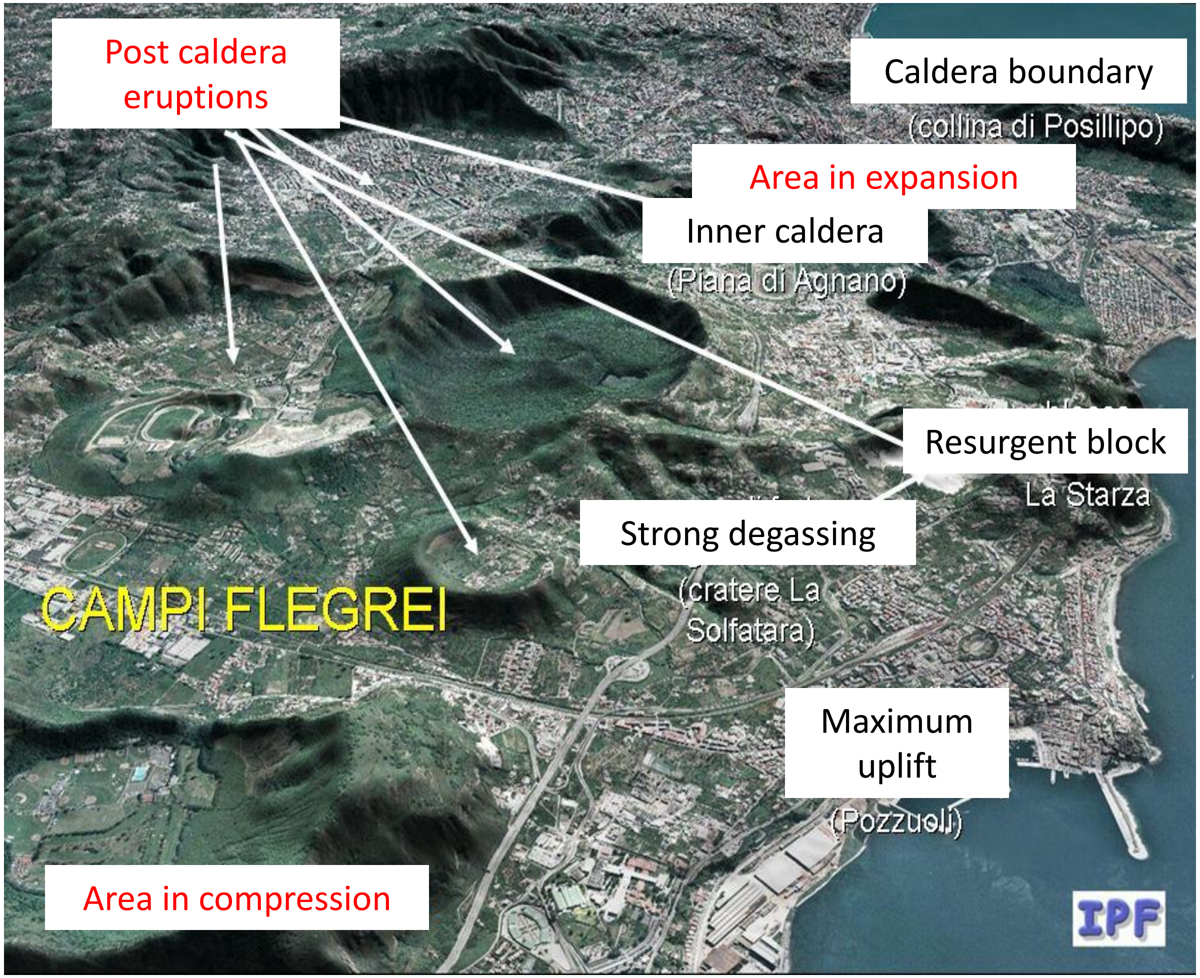
- Preliminary results

- Summary and conclusions

The Campi Flegrei caldera (Italy)

Campi Flegrei (CF) is an active volcanic area located in the Campanian Plain, along the Tyrrhenian margin of the southern Apennines, dominated by the formation of a 12 km large, resurgent caldera.

- The CF caldera was created by two ancient huge eruptions;
- There were **3 eruptive epochs** of volcanic activity lasting some centuries, alternated to periods of rest each long a few millennia;
- Now there is much idrothermal activity and the caldera is in an **unrest state**;
- In the last 15 kyrs the **eruption vents were sparse** in the caldera and most of the eruptions were explosive;
- A few hundreds of thousand people live inside the caldera, and more than 1 million people live in the nearby city of Naples.



(From INGV-Osservatorio Vesuviano)

The research objective

In this study we aim at producing long-term probabilistic maps of vent opening at CF by using new field work and mathematical modelling about past eruptive activity and caldera volcanological features. We built on previous works of Alberico et al. (2002), Orsi et al. (2004) and Selva et al. (2011).

We focused our work on the quantification of the different sources of uncertainty in order to produce median and quantile probabilistic maps of vent opening.

Vent opening maps represent a crucial input to produce probabilistic hazard maps of explosive phenomena (particularly of pyroclastic flows) (see *Bevilacqua et al*, session 4C, room A6, today h. 16:15)

The methodology

The methodology used is based on the assumption that the probability of vent opening can be expressed as a **weighted combination of spatial distributions of relevant variables** (i.e. past vents, faults and fractures). In particular we focused on the quantification of some sources of uncertainty such as:

- **Uncertainty on the spatial location of eruptive vents/fissures (with reference to the last 15 kyrs)**

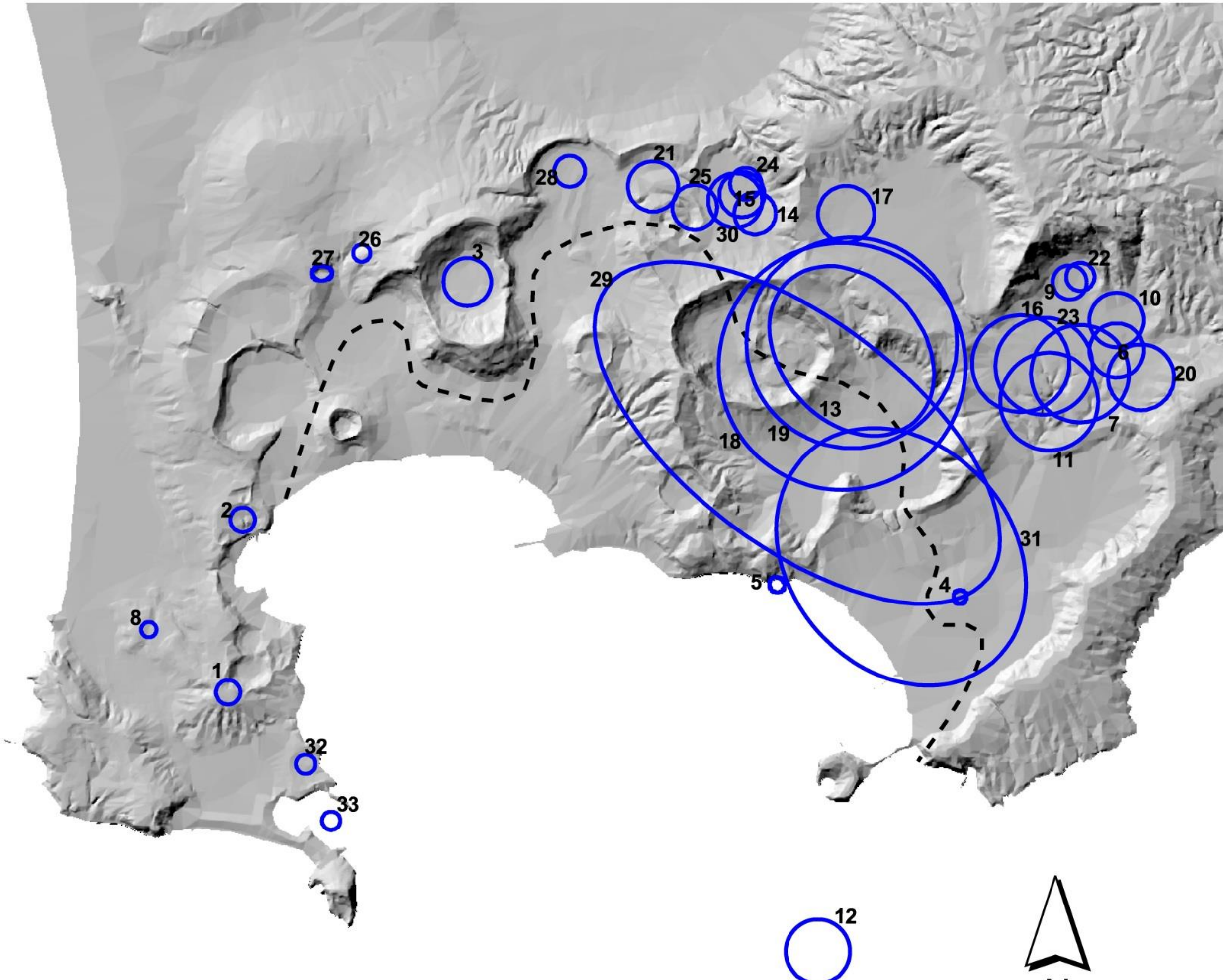
- **Uncertainty due to the incompleteness of the datasets of the variables considered (i.e. past vent openings, faults and fractures)**

- **Uncertainty on the relative weights of the different variables considered**

Vent opening data with uncertainty (1)

Epoch I

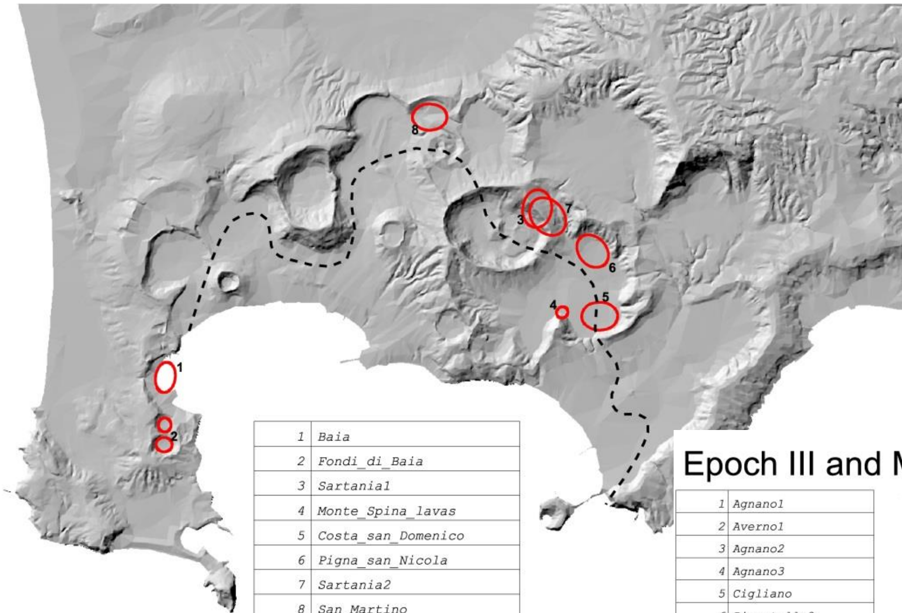
1	Bellavista
2	Mofete
3	Gauro
4	Santa_Teresa
5	La_Pietra
6	La_Pigna1
7	La_Pigna2
8	Torre_cappella
9	Minopoli1
10	Paradiso
11	Soccavo1
12	Gaiola
13	Pomici_Principal
14	Paleo_Pisani1
15	Paleo_Pisani2
16	Soccavo2
17	Soccavo3
18	S4s3_1
19	S4s3_2
20	Soccavo4
21	Paleo_SanMartino
22	Minopoli2
23	Soccavo5
24	Pisani1
25	Pisani2
26	Fondo_Riccio
27	Concola
28	Montagna_Spaccat
29	Pignatiello1
30	Pisani3
31	Casale
32	Bacoli
33	Porto_Miseno



Epoch I: 33 vents (about 10.6-15 kyrs ago)

Vent opening data with uncertainty (2)

Epoch II

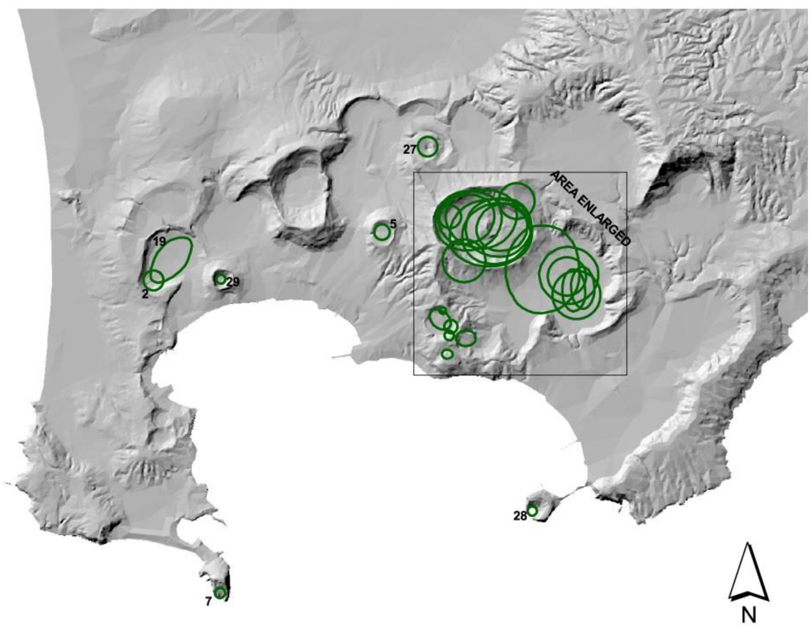


1	Baia
2	Fondi_di_Baia
3	Sartania1
4	Monte_Spina_lavas
5	Costa_san_Domenico
6	Pigna_san_Nicola
7	Sartania2
8	San_Martino

Epoch II: 8 vents
(about 9.1-9.6 kyrs ago)

Epoch III and Mt Nuovo

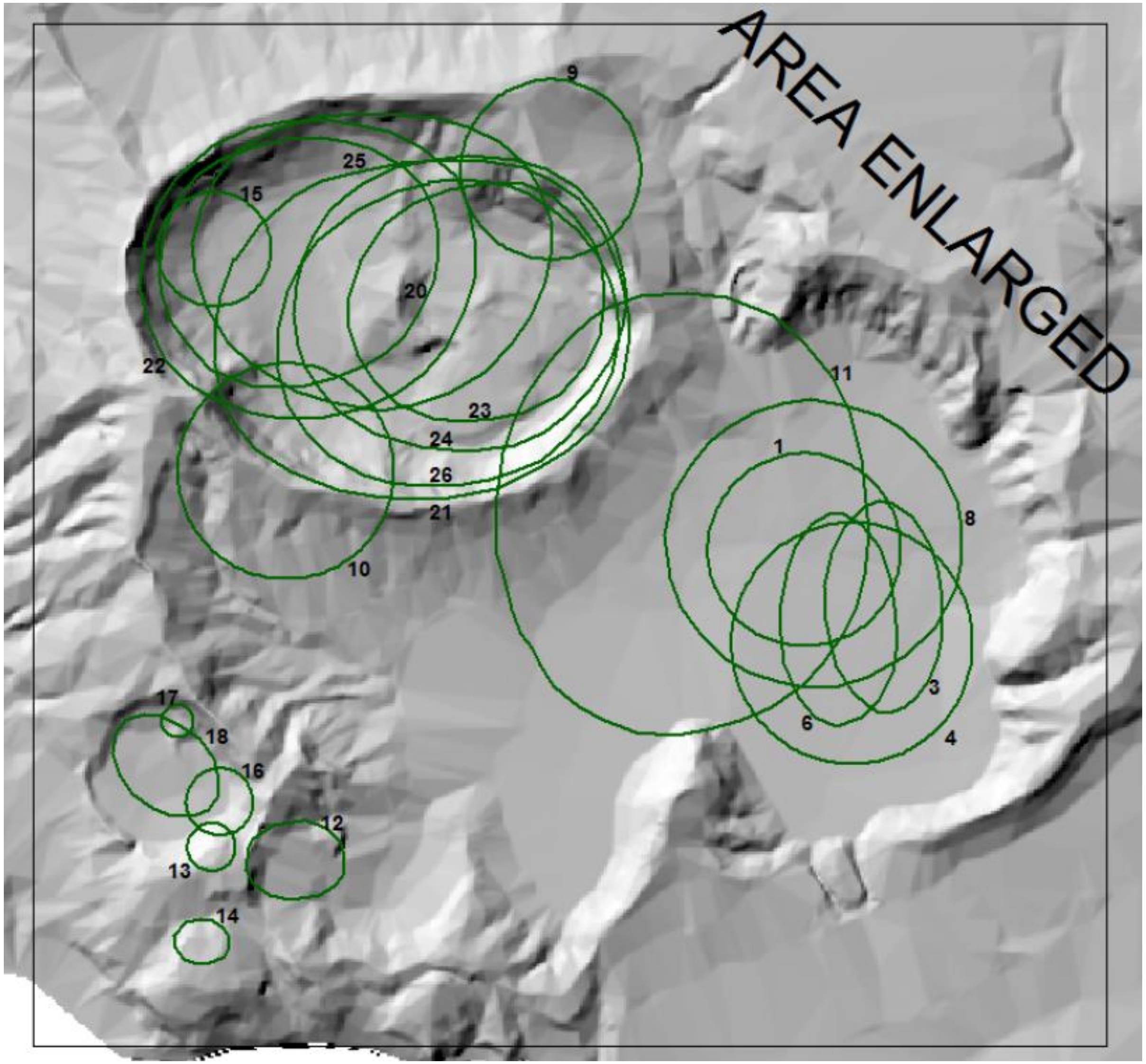
1	Agnano1
2	Averno1
3	Agnano2
4	Agnano3
5	Cigliano
6	Pignatello2
7	Capo_Miseno
8	Monte_santAngelo
9	Paleoastroni1
10	Paleoastroni2
11	Agnano_Mt_Spina
12	S_Maria_dl_Grazie
13	Mt_Olibano_lavas
14	Accademia_lavas
15	Paleoastroni3
16	Olibano
17	Paleosolfatara
18	Solfatara
19	Averno2
20	Astroni1
21	Astroni2
22	Astroni3
23	Astroni4
24	Astroni5
25	Astroni6
26	Astroni7
27	Fossa_Lupara
28	Nisida
29	Monte_Nuovo



Epoch III and Mt Nuovo: 29 vents
(about 3.5-5.5 kyrs ago and 1538 AD)

Vent opening data with uncertainty (3)

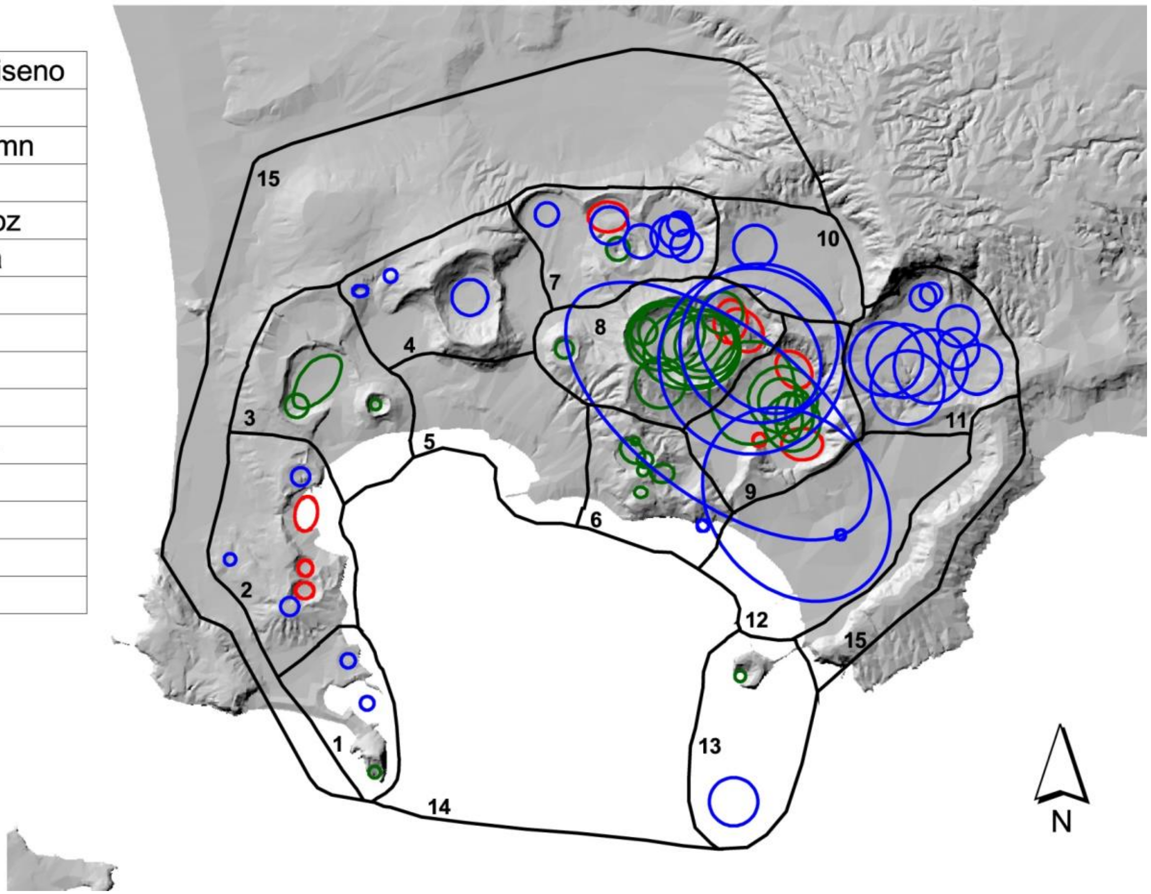
1	Agnano1
2	Averno1
3	Agnano2
4	Agnano3
5	Cigliano
6	Pignatello2
7	Capo_Miseno
8	Monte_santAngelo
9	Paleoastroni1
10	Paleoastroni2
11	Agnano_Mt_Spina
12	S_Maria_dl_Grazie
13	Mt_Olibano_lavas
14	Accademia_lavas
15	Paleoastroni3
16	Olibano
17	Paleosolfatara
18	Solfatara
19	Averno2
20	Astroni1
21	Astroni2
22	Astroni3
23	Astroni4
24	Astroni5
25	Astroni6
26	Astroni7
27	Fossa_Lupara
28	Nisida
29	Monte_Nuovo



Partition of the CF caldera for vent opening

Caldera partition

1	Capo_miseno
2	Baia
3	Averno_mn
4	Gauro
5	Toiano_pz
6	Solfatara
7	Pisani
8	Astroni
9	Agnano
10	Pianura
11	Soccavo
12	Bagnoli
13	Nisida
14	Mare
15	CI



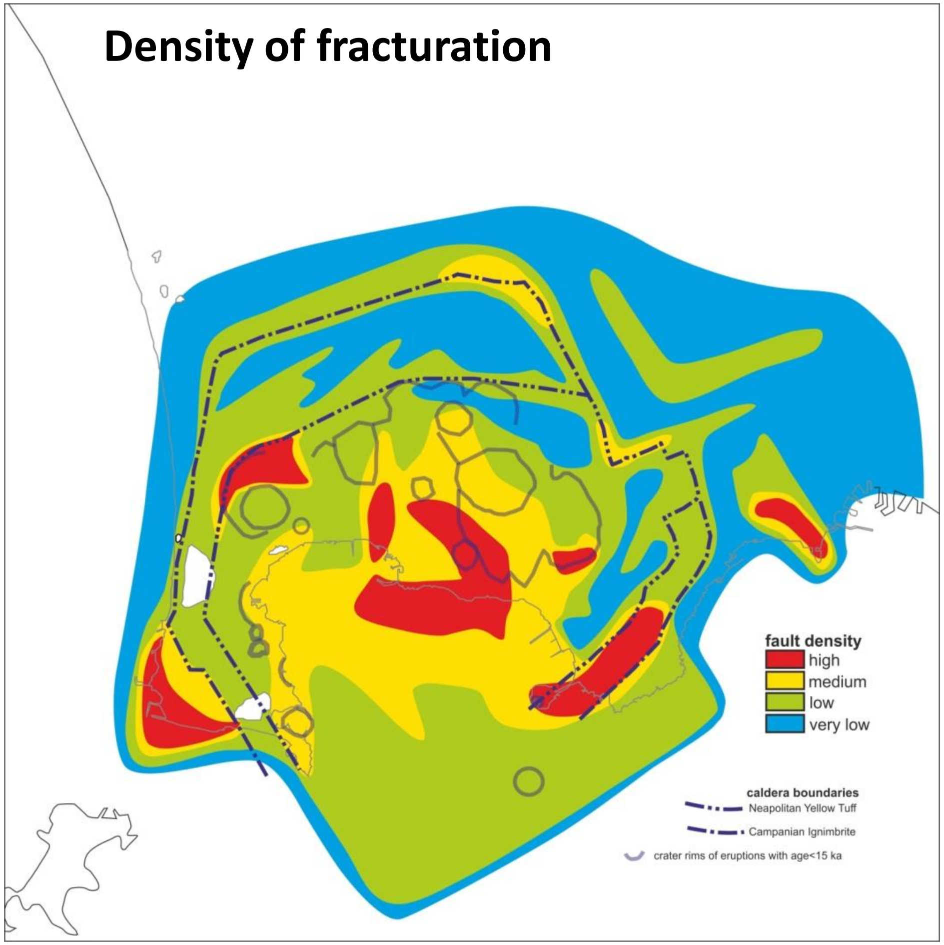
We partitioned the caldera in 15 zones by taking into account the **spatial and temporal clustering** of past vents and the actual **morphological features** of the caldera.

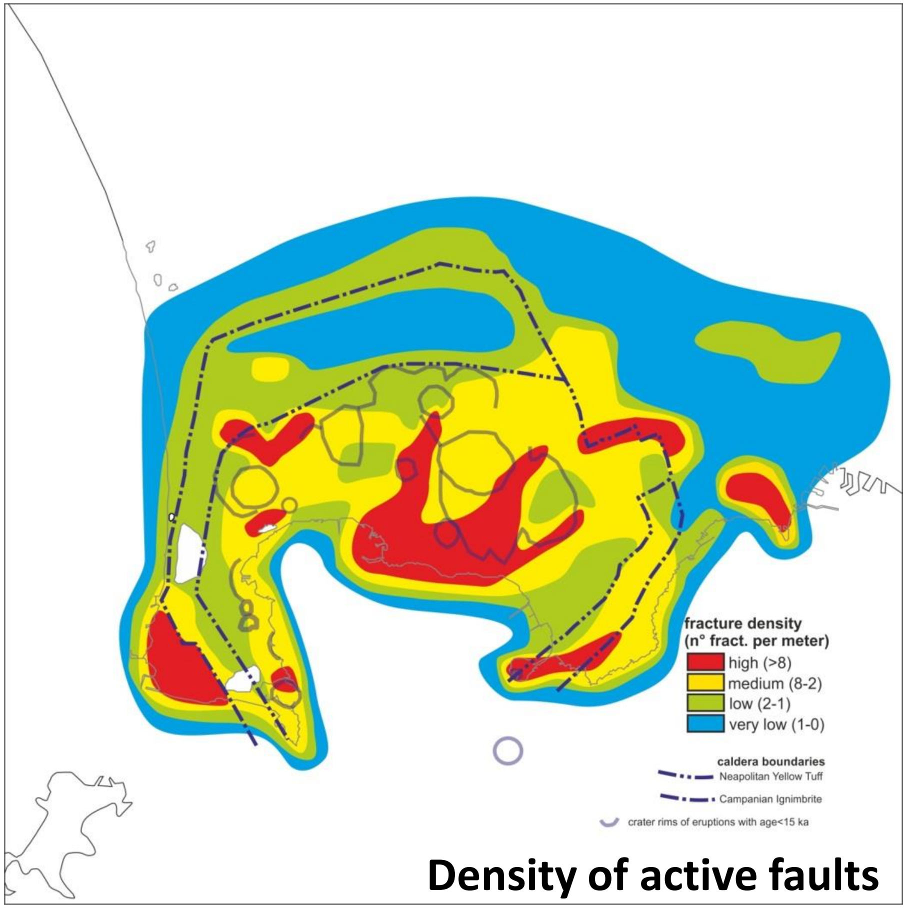
This has the motivation to discriminate between the zones that have a different history of activity, also based on the experts opinion.

We counted the number of ellipses contained in each zone (or the associated fraction contained) obtaining three **maps of the frequency of past vents**, one for each epoch of activity.

Distribution of faults and fractures densities

The fracture map shows the value of density of fracturation, as number of fractures per meter, obtained from discrete sampling.





The fault map shows the value of density of faulting also including the historical deformation patterns.

Uncertainty due to incompleteness of the datasets

The experts also estimated the **percentage of completeness of the datasets**. The complementary percentage (i.e. unmapped past vents, fractures and faults) was assigned to **homeogeneus maps.**

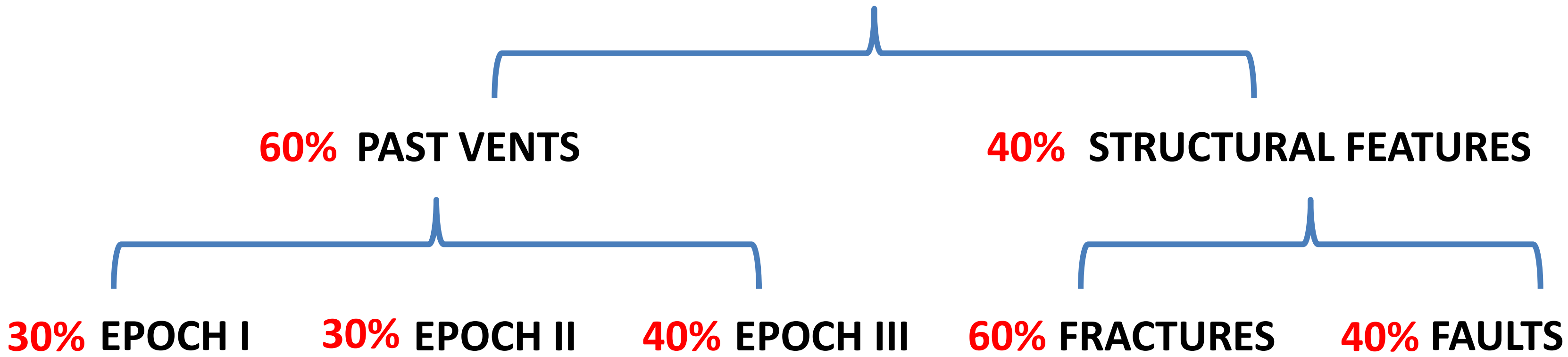
The weight of the unmapped past vents was restricted to the inland portion of the caldera whereas those of unmapped fractures and faults to the whole caldera.

Completeness of datasets (Reliability percentage)

75%	95%	90%	80%	80%
Vents of epoch I	**Vents of epoch II**	**Vents of epoch III**	**Fractures**	**Faults**

Assignment of weights by expert judgement

In order to favor the assignment of weights to the geological features a **simple logic tree** was adopted (all relative weights were scaled to sum to 100%).



The percentages were assigned as **modal values** and the uncertainty about them was then described using triangular distributions.

The weights given to the vents of the three epochs were assumed per single vent and therefore were then **normalized** in proportion to the event number during each epoch (33, 8 and 29 respectively).

We also considered the possibility that the probability of vent opening would be correlated to other **neglected features** of the system. This has been estimated of the order of **10%.**

Preliminary weight estimations

By multipling the weights on the branches of the logic tree we obtained a first estimation of the **relative weights of the sets of variables** considered.

25%	6%	29%	24%	16%
Vents I	**Vents II**	**Vents III**	**Fractures**	**Faults**

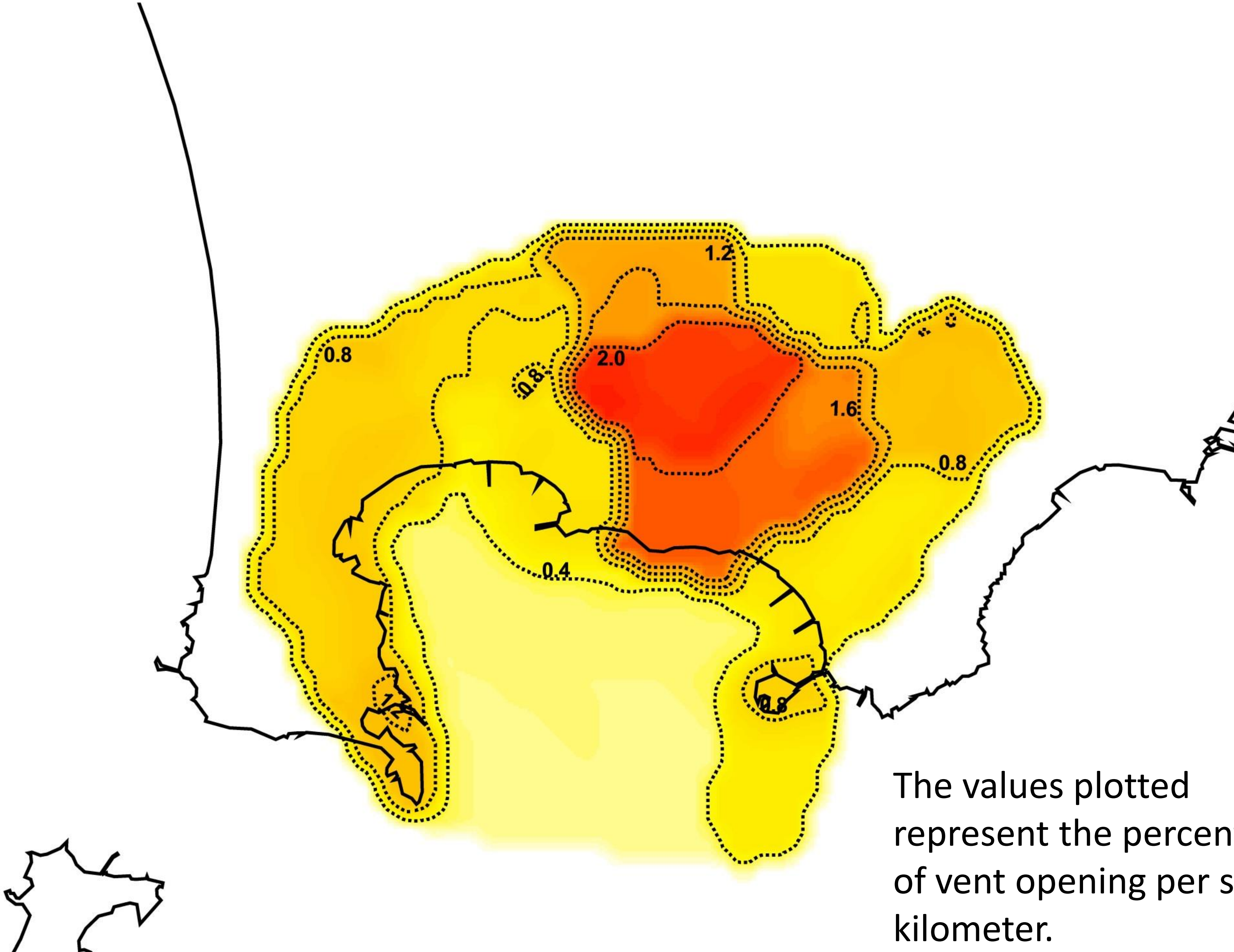
By considering also the uncertainty related to the **incompleteness of datasets and model adopted** we got the following **relative weights of our compound map**:

Homogeneous maps
representing lack of information

8.35%	17.20%
Inland	Whole caldera

16.16%	5.29%	24.20%	17.28%	11.52%
Vents I	**Vents II**	**Vents III**	**Fractures**	**Faults**

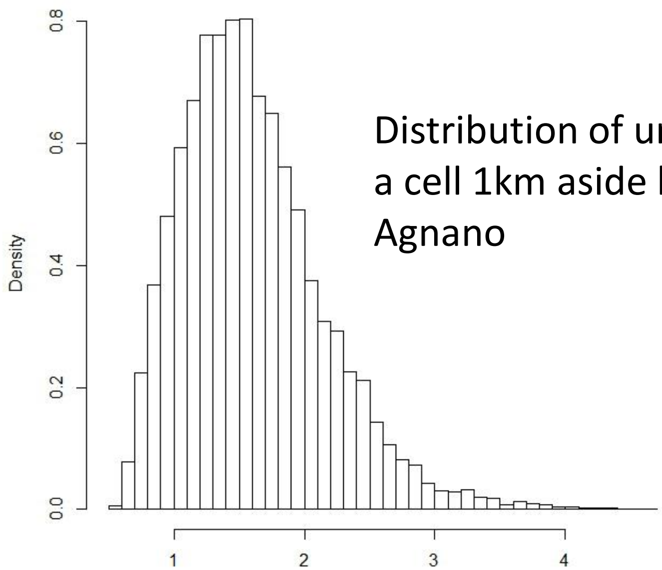
Preliminary probabilistic vent opening map



The values plotted represent the percentage of vent opening per square kilometer.

Preliminary probabilistic vent opening map

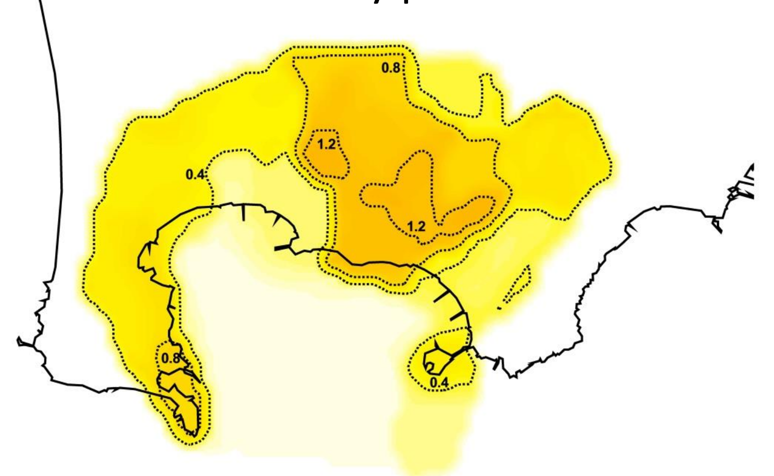
By considering the above described uncertainty sources and using Monte Carlo simulation we obtained the **5% and 95%ile maps of probability of vent opening** as well as specific distributions of uncertainty in specific places.



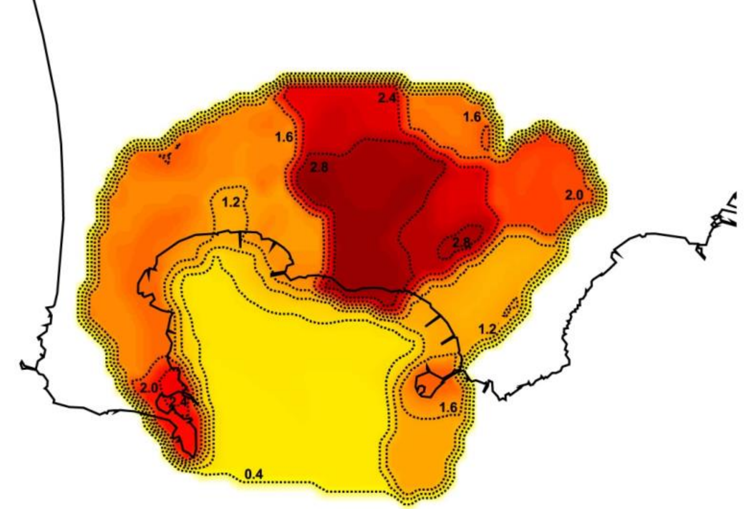
Distribution of uncertainty in a cell 1km aside located in Agnano

To express the uncertainty about the weight just given with the homogeneous maps we simulated to concentrate each part of it on single zones of the partition randomly extracted during this Monte Carlo simulation.

5th uncertainty percentile



95th uncertainty percentile



Summary and conclusions

- **New field data** aimed to identify the location of past vents were produced by explicitely evaluating their uncertainty.

- A preliminary **probabilistic map of vent opening**, able to incorporate the associated **uncertainty**, was produced by assigning relative weights to different geological features by using **expert judgement**.

- First results highlighted a main **wide region of high probability** of vent opening approximately located in the area of Agnano-Astroni-Solfatara. Significant probabilities were however predicted all over the caldera.

- **Results need to be consolidated** by refining and extending the datasets and the expert judgement methods used.

Acknowlegments

- **Project Speed** “Scenari di pericolosità e danno per i vulcani della Campania”, Dipartimento della Protezione Civile (Italy) and Regione Campania, 2007-2010.

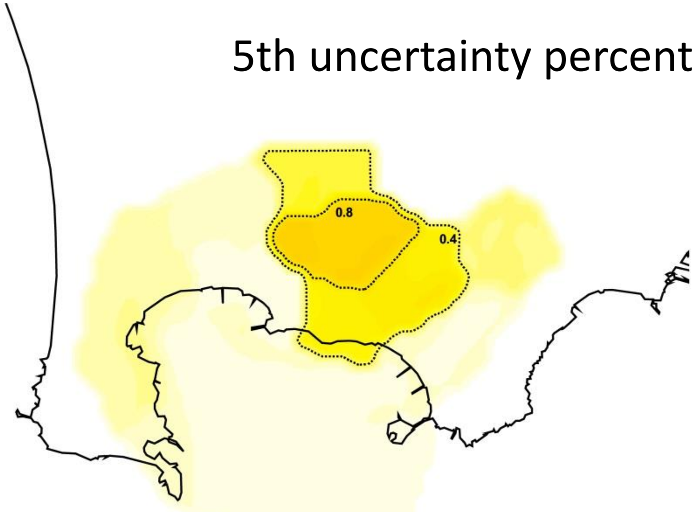
- **Project DPC-V1** “Valutazione della pericolosità vulcanica in termini probabilistici”, Dipartimento della Protezione Civile (Italy), 2012-2013.

Uncertainty using Dirichlet distributions

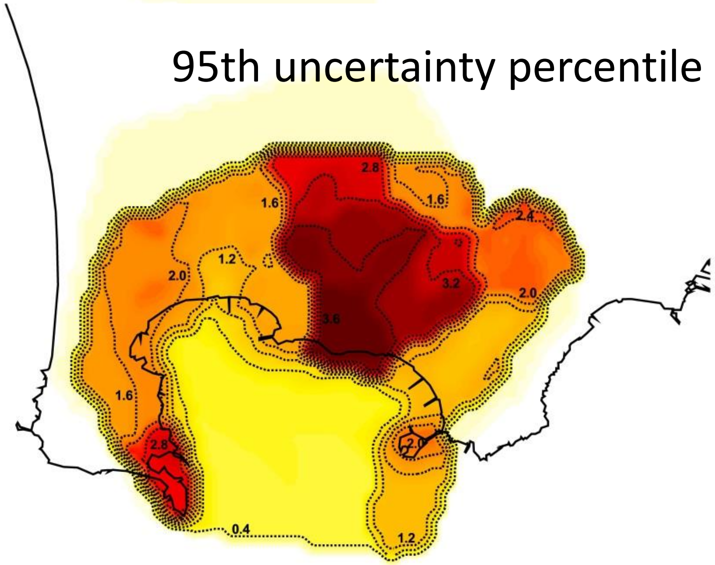
An alternative method to assign an uncertainty distribution to the map is to use a **Dirichlet distribution** of confidence around the 15 values of probabily of the zones of the partition.

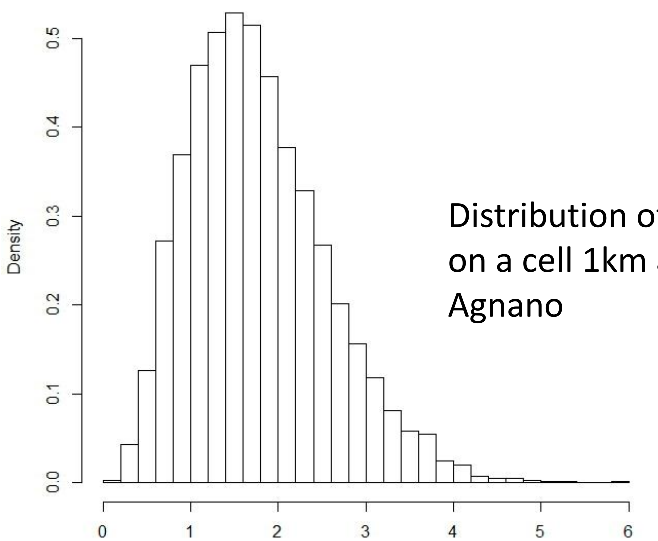
A drawback of this approach is the fact that the uncertainty is **parametrized by only a single scalar** representing the dispersion around the mean map: in general higher values will have a higher uncertainty and this is not always the best choice.

5th uncertainty percentile



95th uncertainty percentile





Distribution of uncertainty on a cell 1km aside located in Agnano