Assessing conditional effects of vent location, event scale and time forecasts on pyroclastic density currents hazard maps at Campi Flegrei caldera (Italy)

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The volcanological problem

Campi Flegrei is an active volcanic area in the Campanian Plain, dominated by a 12 km large caldera.

This study concerns Campi Flegrei **long-term hazard assessments** about pyroclastic density currents (PDC), primarily based on past eruption data and on the structural features of the volcanic system.

The forecasting model adopted for PDC invasion hazard mapping includes:

1) the large uncertainty on **future vent location**,

2) the unpredictable **scale of future activity**,

3) the complexity of the long-term **temporal forecasts.**

Mosaic of orthophotos of Campi Flegrei caldera and surrounding areas.


A yellow line separates western and eastern sectors of the caldera with different history of activity.

Research objective and methodology

We combined three types of data and associated distributions:

I. a probability map for **the location** of the next eruptive vent

II. a probability distribution for **the size** of the next PDC, i.e. without selecting a reference scenario

III. a time-space probability model for **the time** of the next eruption, able to describe the vent clustering.
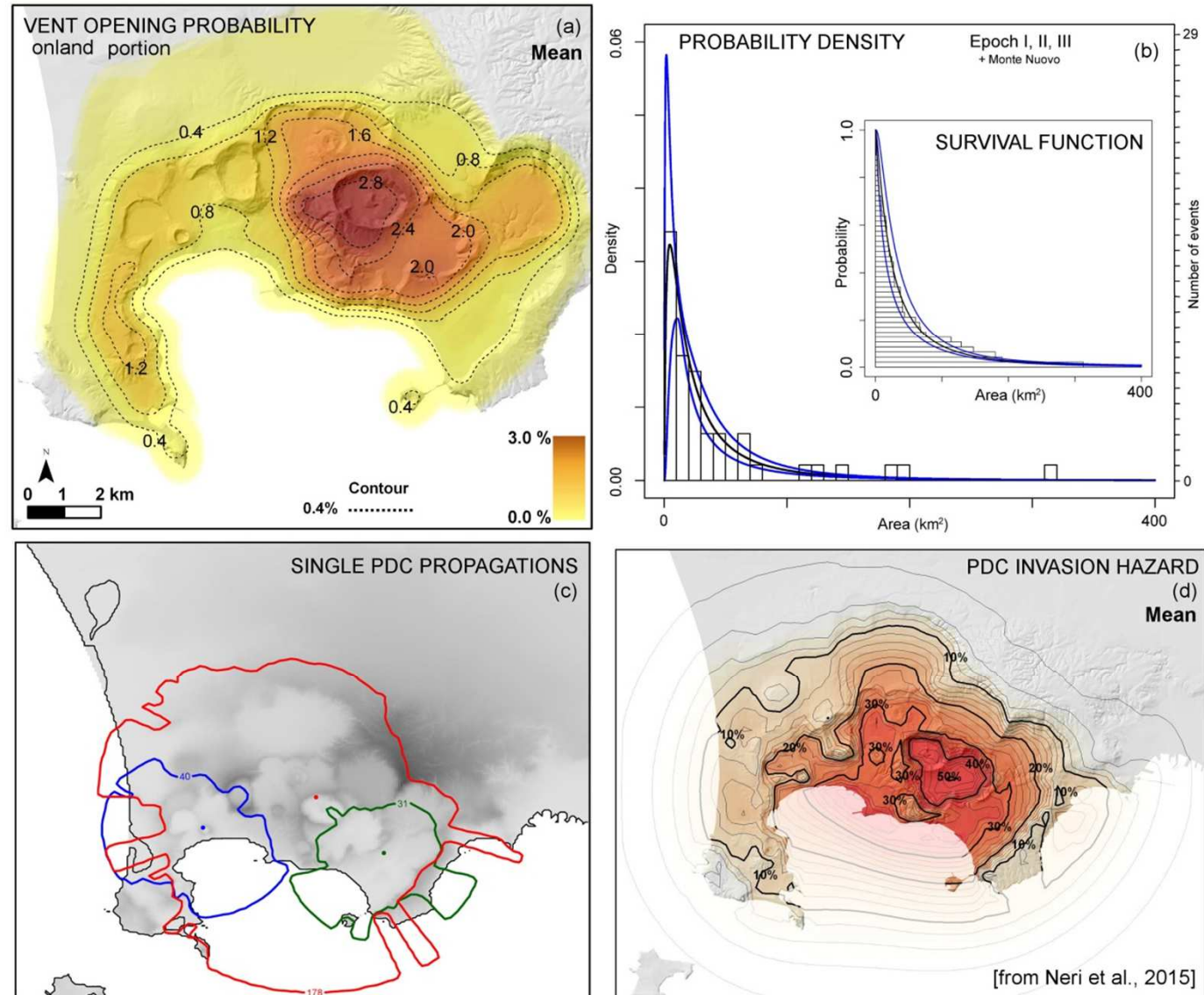
With a **simplified PDC invasion model** (*box model*), we repeated a large number of PDC invasion samples, changing vent location, scale and time.

Examples of probability density functions modeling:
(a) vent opening location [Bevilacqua et al. 2015],
(b) areal size of PDC [Neri et al. 2015],
(c) examples of single PDC propagations,
(d) PDC invasion hazard map.

PDC invasion hazard map conditional to an explosive event - not including time

PDC invasion hazard map assuming a single vent located onland. Contours and colours indicate the percentage probability of PDC invasion **conditional on the occurrence** of an explosive eruption.
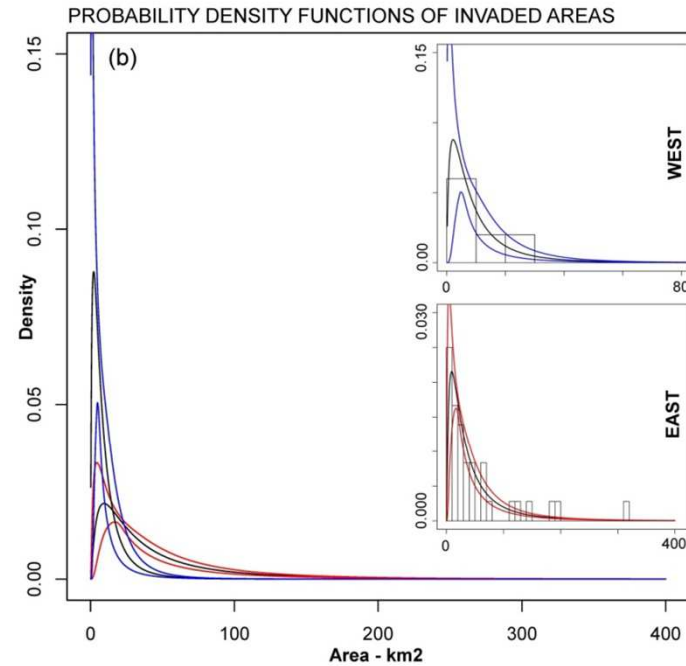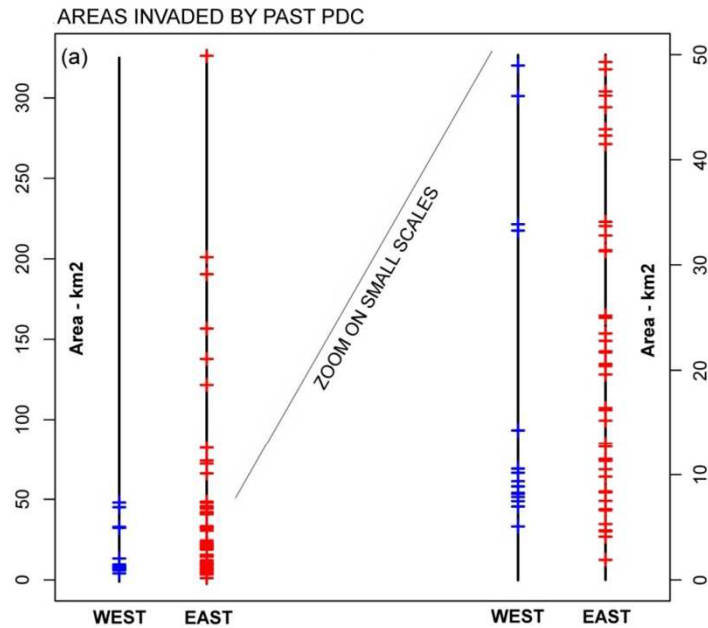

Neri et al. [2015].
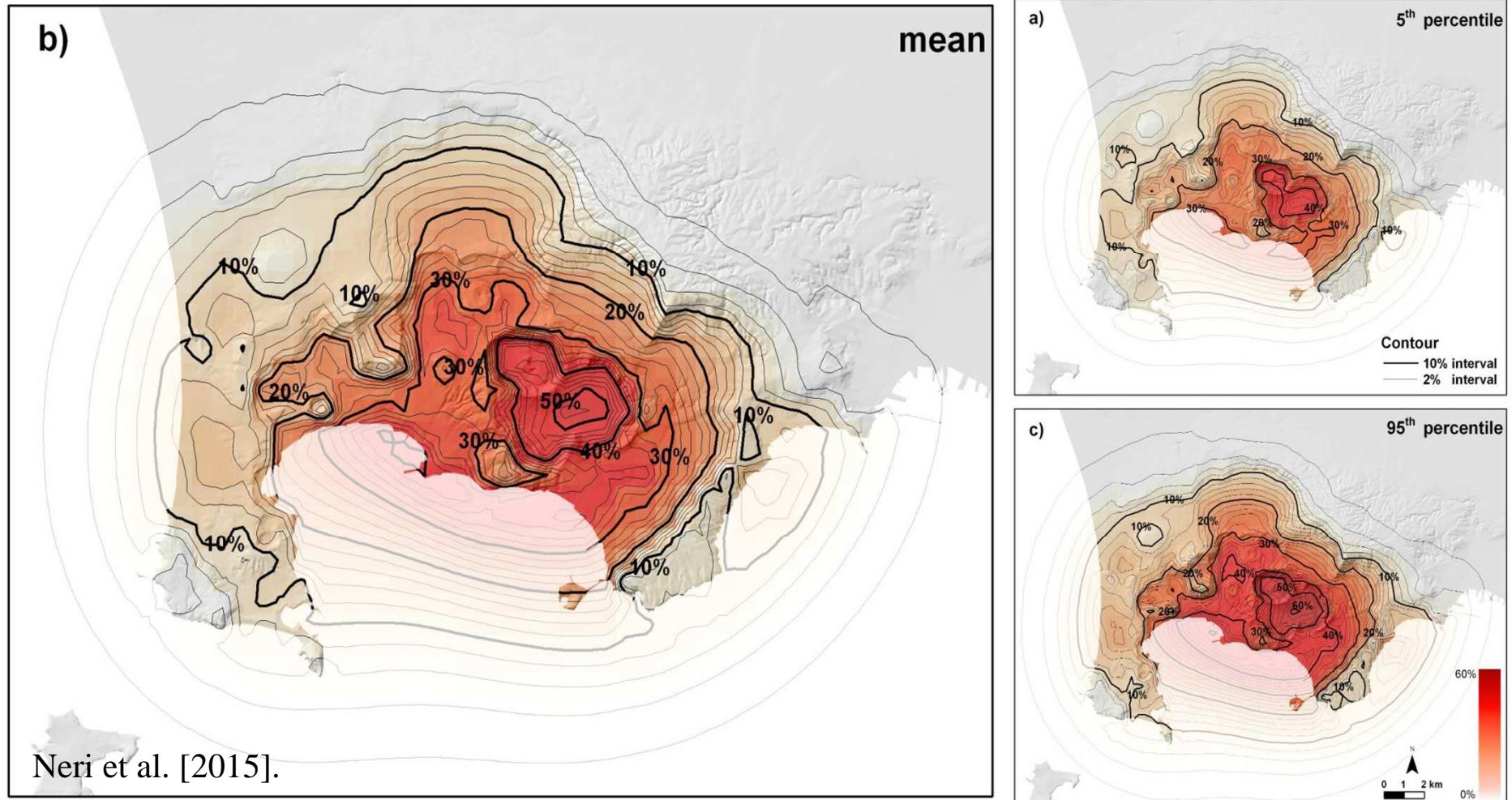
The probability maps are affected by epistemic uncertainty: for this reason we reported the **mean, 5th and 95th percentile** values for the PDC invasion hazard estimates.
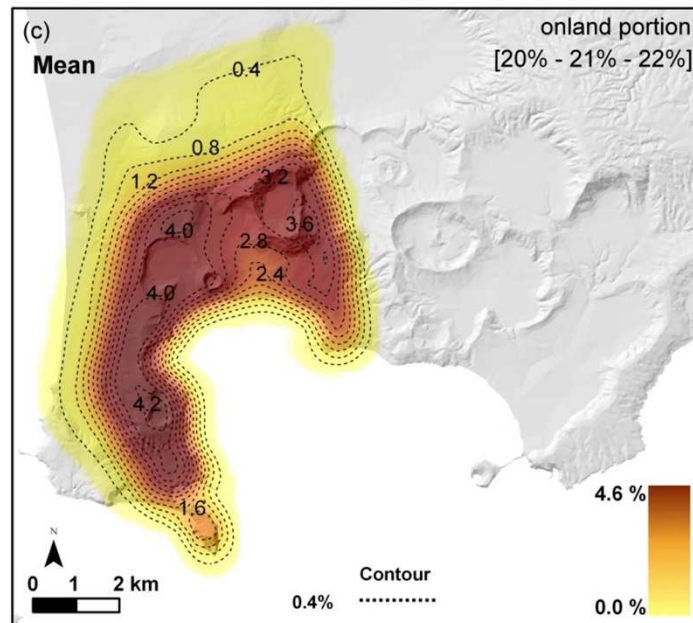
Eastern vs Western sectors of the caldera

Differences between the eastern and western sectors in terms of the past PDC areal sizes in the last 15 ka.
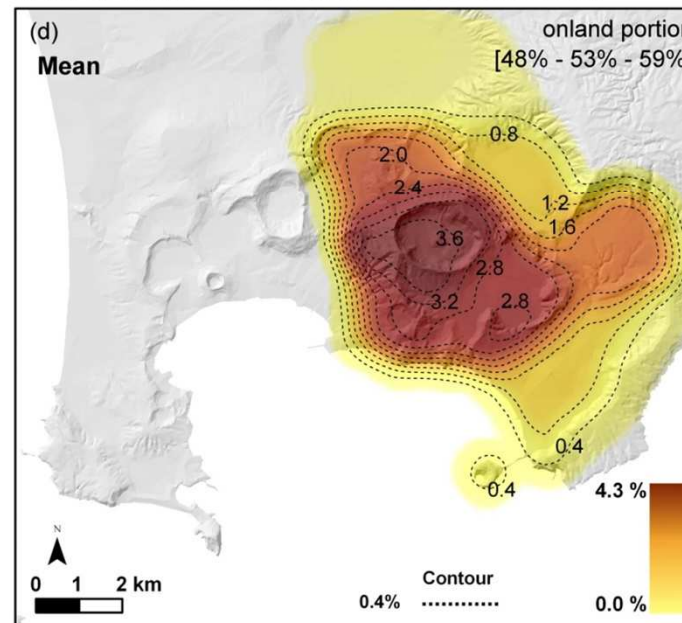
The **eastern sector** had a **significantly greater number of eruptive events** and **larger eruptive scales**.

(a) **Areas invaded by past PDC**, eastern and western sectors. Each coloured line is an event.

(b) **probability density functions for the PDC invasion areas**. The black curve is the mean and the colored curves are the 5*th* and 95*th* percentiles.
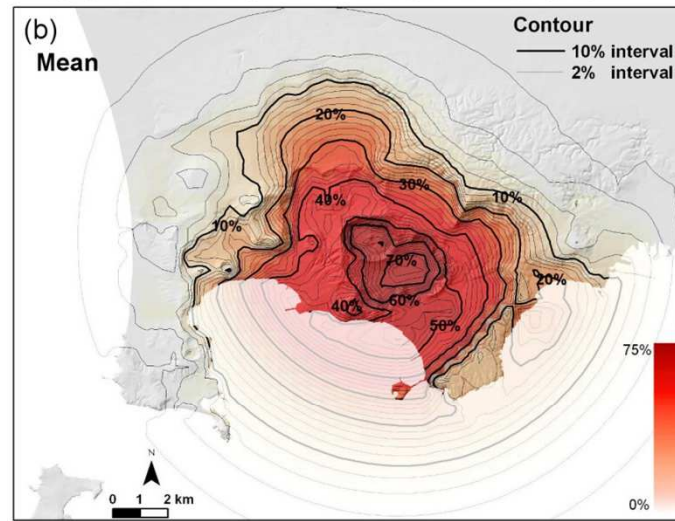
(c,d) **conditional vent opening maps** in the two sectors.

PDC invasion hazard maps – Vent opening in specific sectors (East/West)

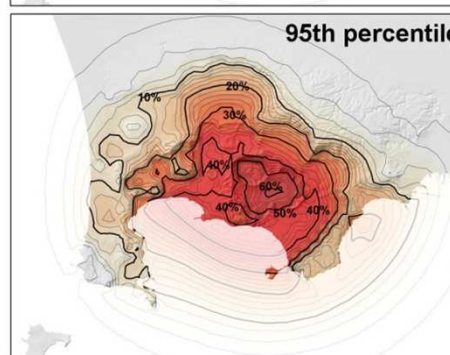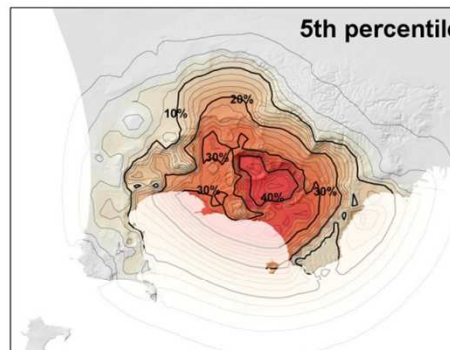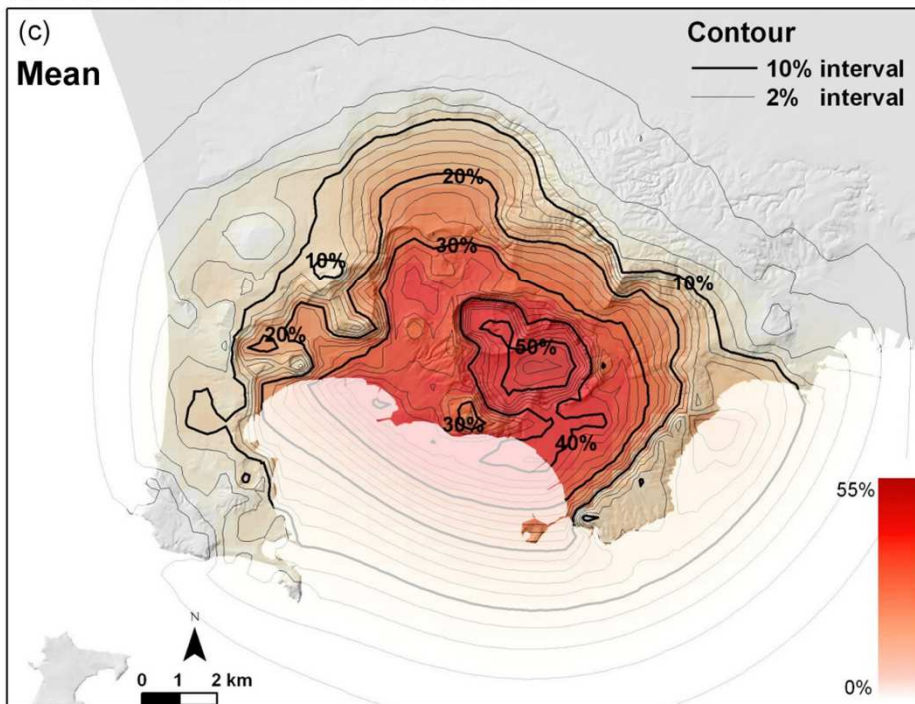PDC ORIGINATING IN THE WESTERN SECTOR
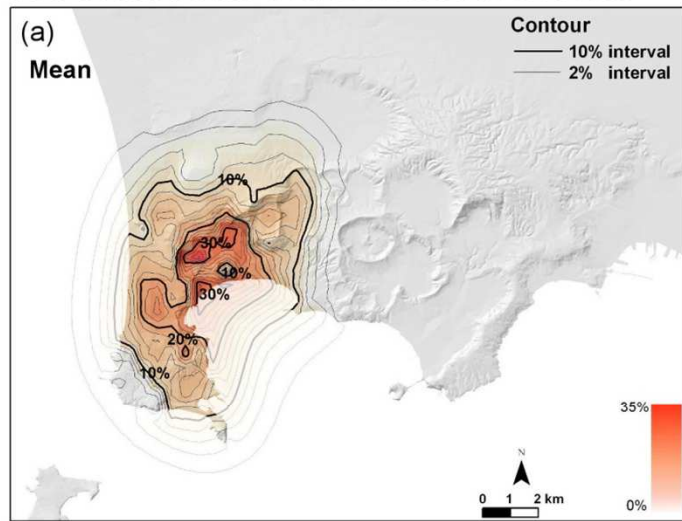
PDC ORIGINATING IN THE EASTERN SECTOR

PDC SIZE DEPENDENT ON THE SECTOR

PDC invasion hazard maps computed under assuming **different PDC scales** as a function of the sector.

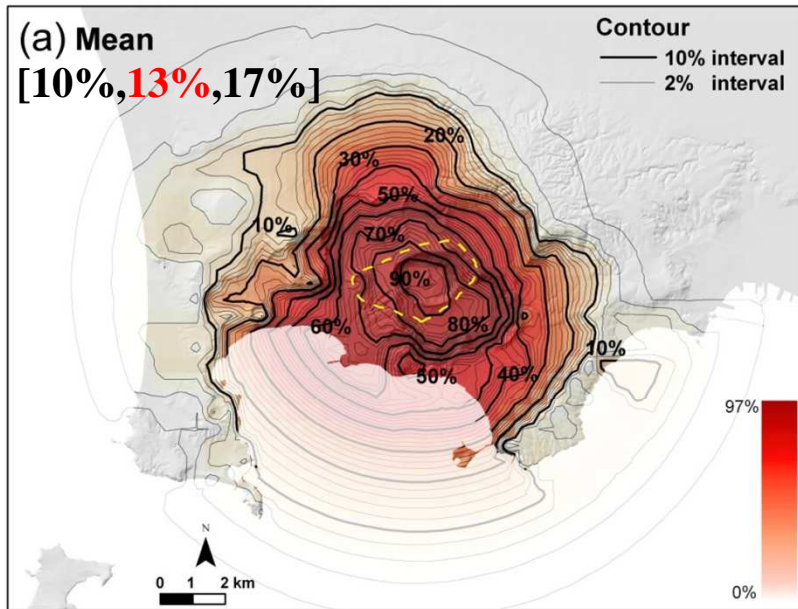(a) - (b) are conditional on the occurrence of a PDC originating inside a specific sector;
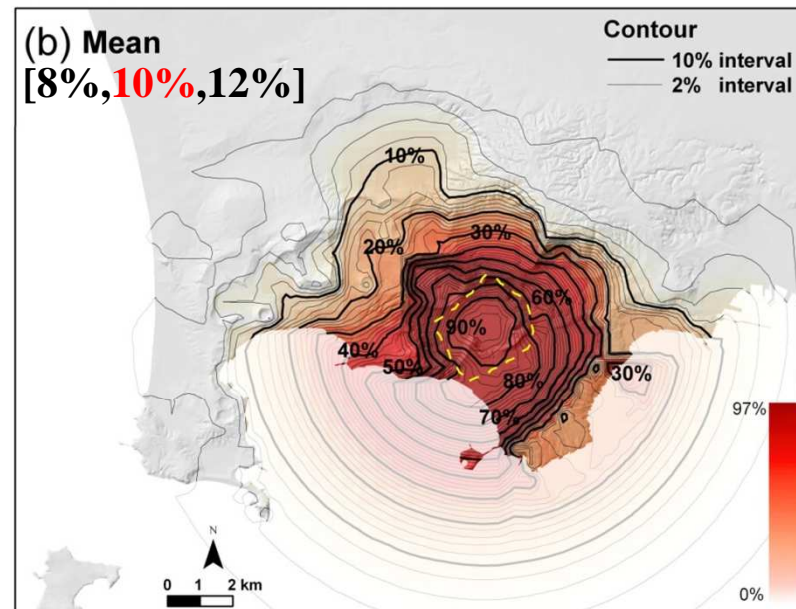
(c) assume different PDC areal sizes distributions for the PDC originating in the two sectors.

PDC invasion hazard maps – Vent opening in specific zones of the caldera


ASTRONI

(a) Mean
[10%,13%,17%]

Contour
— 10% interval
— 2% interval

20%
30%
50%
10%
70%
90%
60%
80%
50%
40%
10%

97%

N

0 1 2 km

0%

AGNANO

(b) Mean
[8%,10%,12%]

Contour
— 10% interval
— 2% interval

10%
20%
30%
60%
40%
50%
90%
80%
30%
70%

97%

N

0 1 2 km

0%

AVERNO - MONTE NUOVO

(c) Mean
[4%,5%,6%]

Contour
— 10% interval
— 2% interval

20%
40%
80%
10%
60%
30%

86%

N

0 1 2 km

0%

CENTRAL EASTERN ZONES

(d) Mean
[28%,32%,40%]

Contour
— 10% interval
— 2% interval

30%
40%
20%
50%
80%
10%
70%
60%
60%

88%

N

0 1 2 km

0%

Mean PDC invasion hazard maps conditional on an explosive eruption in originating in a **specific zone of the caldera**.
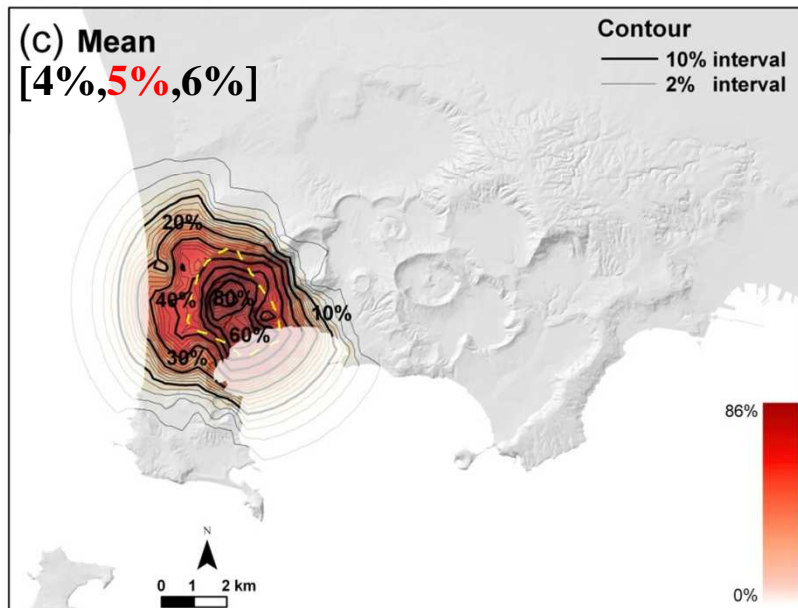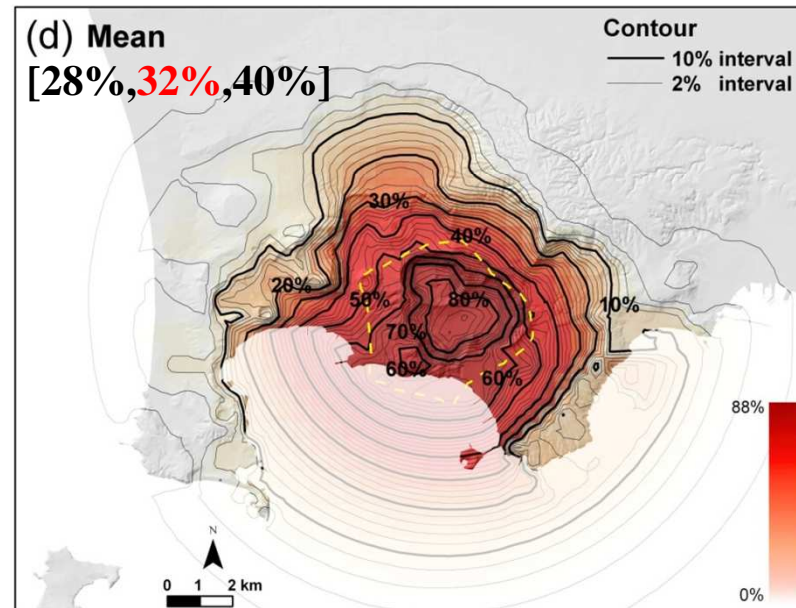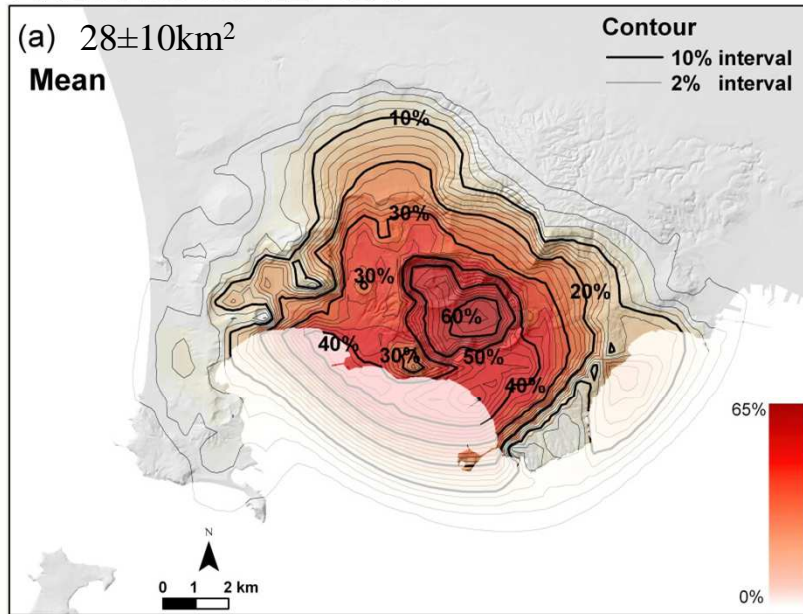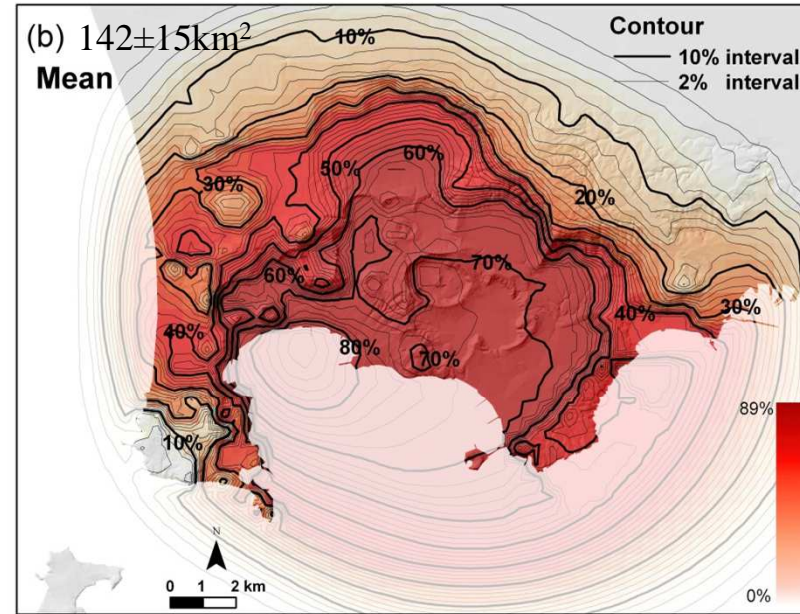
Percentages reported in bold are the **vent opening probabilities** inside each selected zone according to the **vent opening maps** of Bevilacqua et al. [2015].

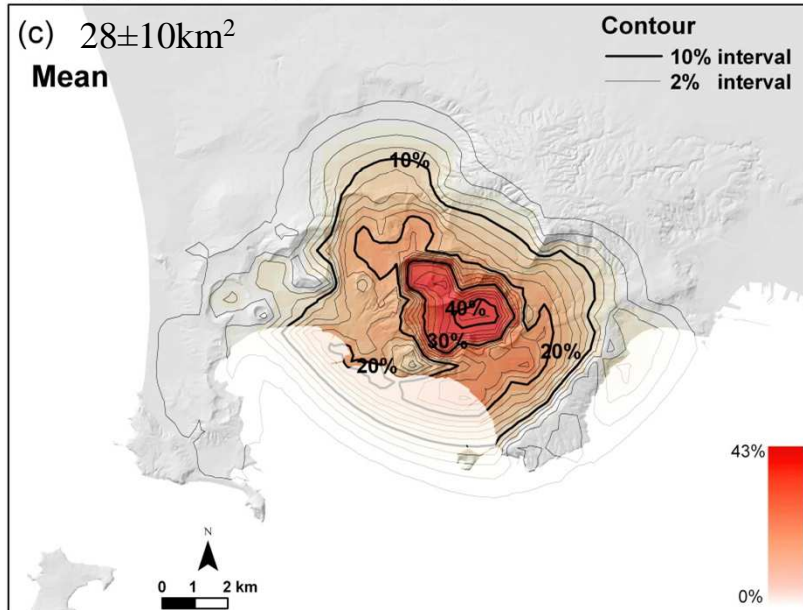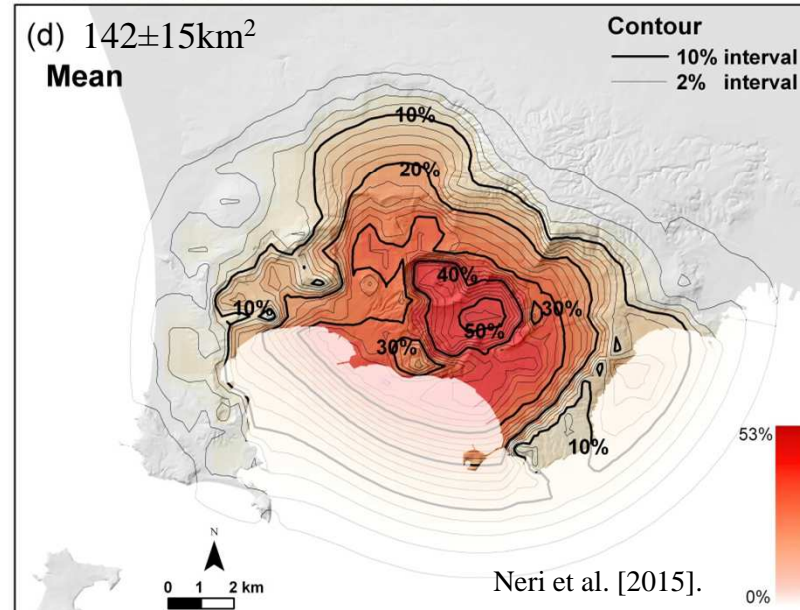# PDC invasion hazard maps – Ranged vs fixed scales

FIXED PDC SCALE - 60%

(a) 28±10km²
Mean

Contour
— 10% interval
— 2% interval

10%
30%
30%
60%
40% 30% 50%
40%
20%

65%
0%

N
0 1 2 km

FIXED PDC SCALE - 95%

(b) 142±15km²
Mean

Contour
— 10% interval
— 2% interval

10%
50% 60%
30%
20%
60%
70%
40%
30%
80% 70%
40%
30%
10%

89%
0%

N
0 1 2 km

BOUNDED PDC SCALE < 60%

(c) 28±10km²
Mean

Contour
— 10% interval
— 2% interval

10%
40%
30%
20%
20%

43%
0%

N
0 1 2 km

BOUNDED PDC SCALE < 95%

(d) 142±15km²
Mean

Contour
— 10% interval
— 2% interval

10%
20%
40%
10% 30%
30% 50%
10%

53%
0%

Neri et al. [2015].

N
0 1 2 km

Mean PDC hazard maps computed under different assumptions concerning the scale.

Percentages reported are:
(a) -(b) **bounding limits** for invasion areal size probability distribution;

(c) - (d) **fixed areal sizes**, assumed as reference scenarios varying only vent location.
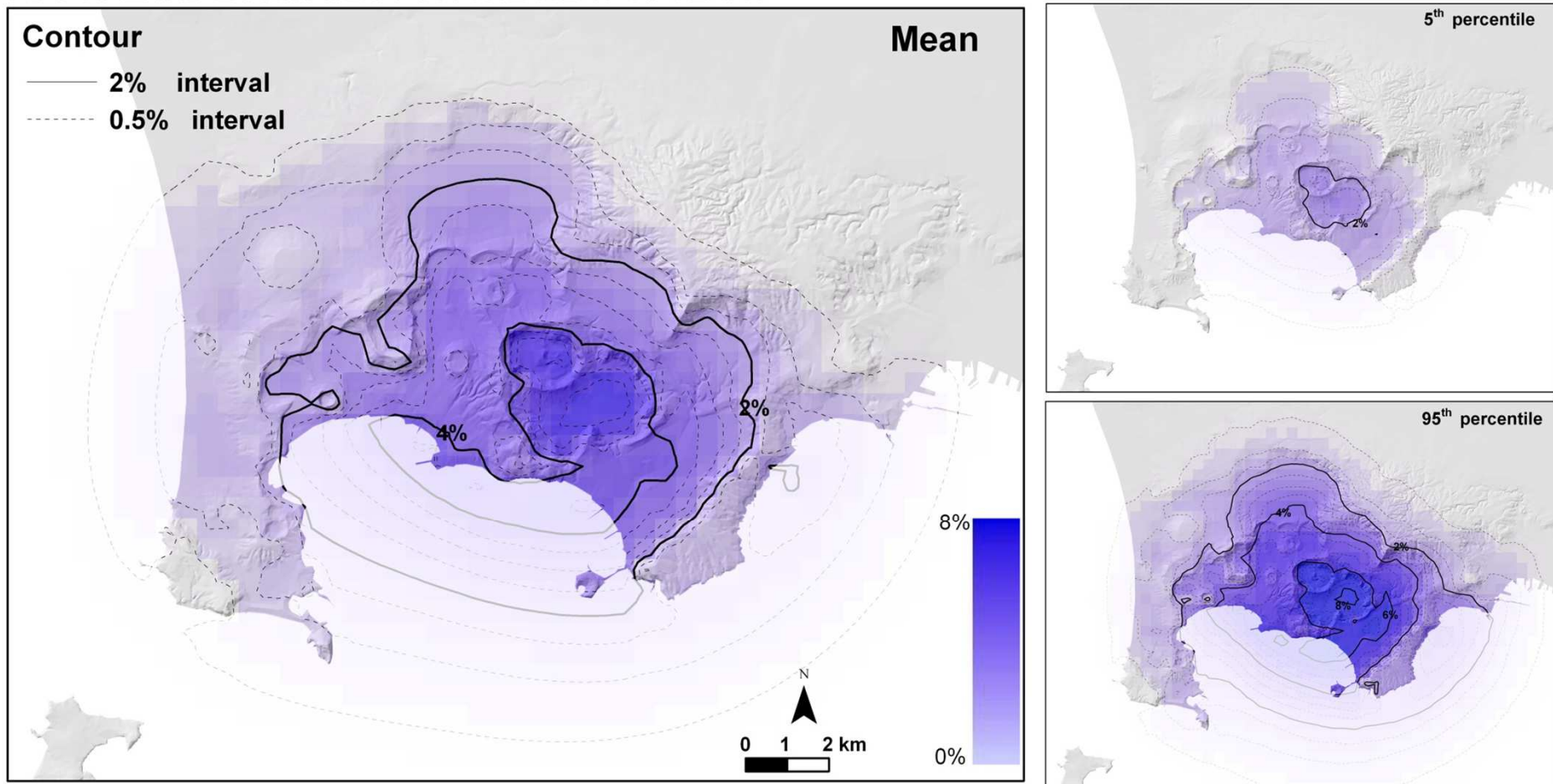
PDC invasion hazard maps – <u>10 years</u>

A probability density function for the **remaining time** before the next eruption has been calculated with a long-term subdomain specific Poisson-type process [see Bevilacqua et al., 2016].

For producing these maps we assumed that Monte Nuovo was the **beginning of a new epoch of eruptive activity** similar to the previously occurred ones.
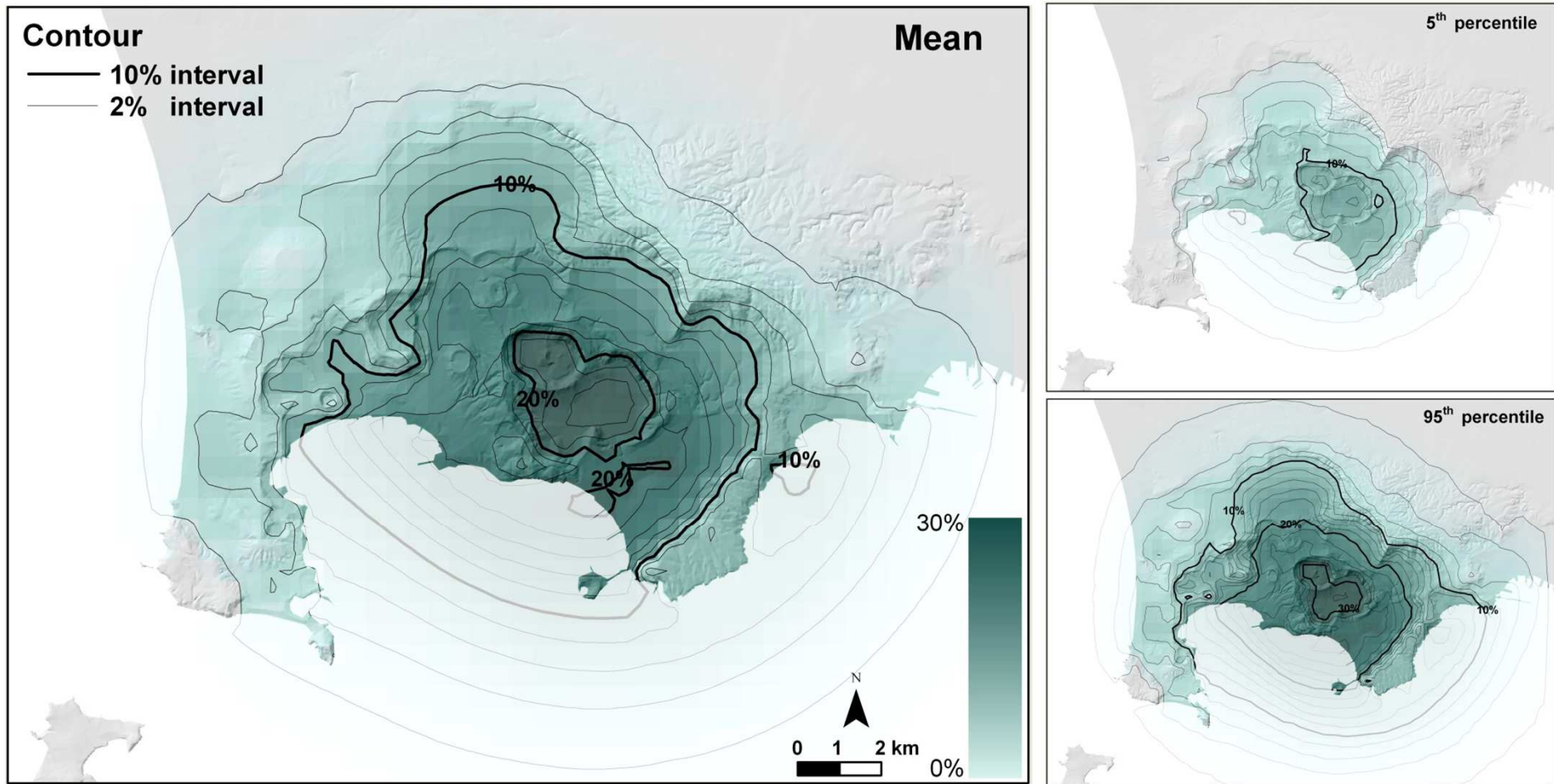
PDC invasion hazard maps – <u>50 years</u>

The model naturally generates clusters of events in space-time and includes the effects of epistemic uncertainty affecting past record data.

For this longer time window the PDC hazard also includes the potential for sequences of multiple events.

PDC HAZARD ESTIMATES FOR THE NEXT 50 YEARS

Concluding remarks

- **Quantitative maps** of PDC invasion hazard at Campi Flegrei have been produced exploring a range of volcanological assumptions. The maps explicitely consider the variability of the **three main future unknowns** of the system (vent location, eruption scale, time).

- PDC invasion maps considering the **western and eastern sectors separately** result significantly different from those obtained considering the caldera as homogeneous. Maps significantly change also based on the temporal period assumed.

- **Specific scenarios** were produced concerning the poin of origin of the PDC and its areal extent. This represents a versatile tool for exploring the hazard variability.

- By assuming that Monte Nuovo represents the **start of a new epoch of activity**, PDC invasion hazard maps for the next 10 and 50 years time window have been produced. The most exposed area (i.e. Agnano-Astroni) reaches average hazard values above 5.5% in the next 10 years and around 25% in the next 50 years.

Publications

Quantifying volcanic hazard at Campi Flegrei caldera (Italy) with uncertainty assessment: I. Vent opening maps, *A. Bevilacqua , R. Isaia, A. Neri, S. Vitale , W. P. Aspinall, M. Bisson, F. Flandoli, P. J. Baxter, A. Bertagnini, T. Esposti Ongaro, E. Iannuzzi, S. Orsucci, M. Pistolesi, M. Rosi,* J Geophys Res, 120 (4), 2309-2329.

Quantifying volcanic hazard at Campi Flegrei caldera (Italy) with uncertainty assessment: II. Pyroclastic density current invasion maps, *A. Neri, A. Bevilacqua, T. Esposti Ongaro, R. Isaia, W. P. Aspinall, M. Bisson, F. Flandoli, P. J. Baxter, A. Bertagnini, E. Iannuzzi, S. Orsucci, M. Pistolesi, M. Rosi, S. Vitale*, J Geophys Res, 120 (4), 2330-2349.

Temporal models for the episodic volcanism of Campi Flegrei caldera (Italy) with uncertainty quantification, *A. Bevilacqua, F. Flandoli, A. Neri, R. Isaia, and S. Vitale*, J. Geophys. Res. Solid Earth, 121, doi:10.1002/2016JB013171.

Doubly Stochastic Models for Volcanic Hazard Assessment at Campi Flegrei Caldera, *A. Bevilacqua*, Theses, 21, Edizioni della Normale, Birkhäuser/Springer.

Acknowlegments