Probabilistic invasion maps of long-term pyroclastic density current hazard at Campi Flegrei caldera (Italy)

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Outline of the talk

- The **problem** and the **objective**
- The **methodology** adopted
- **Input data** and pyroclastic density current (PDC) **invasion models** used
- Some **mapping results**
- Concluding **remarks**

The problem

Campi Flegrei (CF) caldera is an active volcanic system characterized by:

1) mostly **explosive activity** (aboundance of PDC)
2) a variety of **eruptive scales**
3) **scattered volcanic vents**

A few **hundred thousands people** live nowdays in the areas directly exposed to **pyroclastic density currents** hazard

Satellite image of Campi Flegrei caldera (Google)

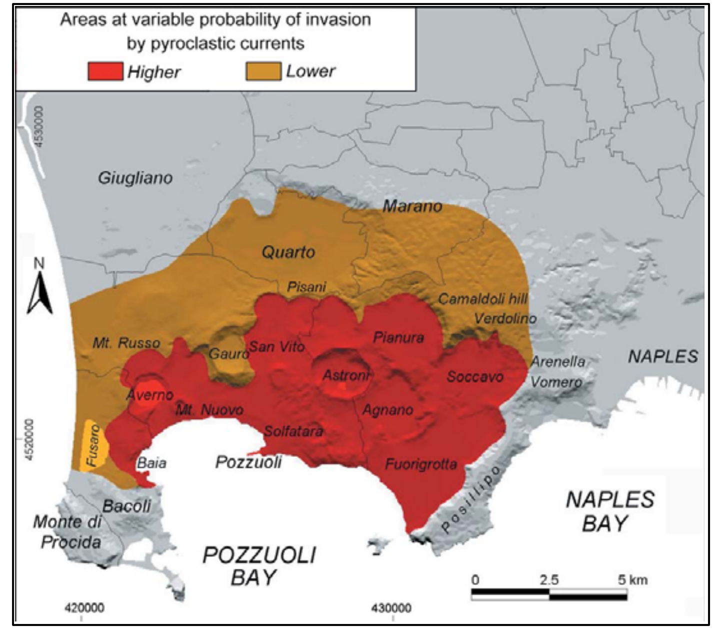
PDC hazard mapping is a crucial step to assess the volcanic risk (short and long-term) and design appropriate mitigation actions

The objective

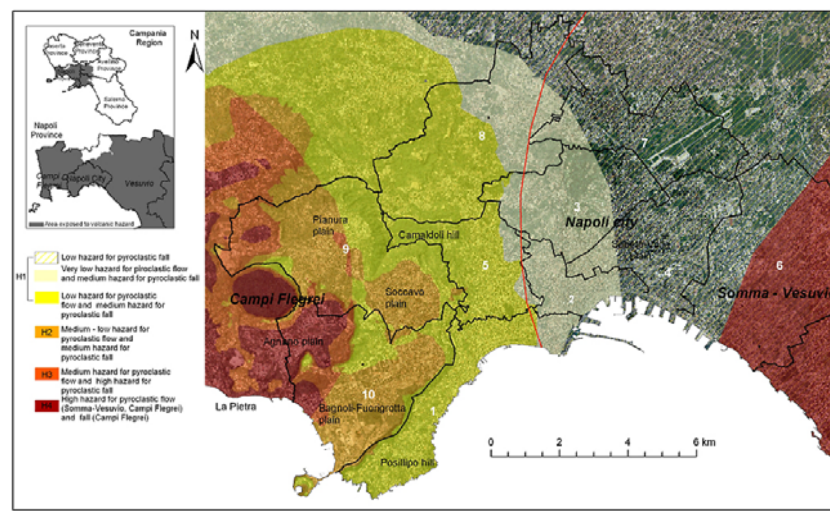
The problem is particularly challenging due to 1) the large uncertainty on **future vent location** 2) the unpredictable **scale of future activity**, and 3) the **complex dynamics of PDC** (particularly over the 3D caldera topography)

Previous studies have produced **qualitative and quantitative maps** accounting for some of these complexities (ref. last 5 kyrs)

Nevertheless, **quantitative probabilistic mapping of PDC invasion**, possibly able to account for the **intrinsic uncertainties** of the system, is needed for hazard assessment



(From Orsi et al., 2004)



(From Alberico et al., 2011)

The methodology

In order to produce a long-term probability map of PDC hazard of the CF caldera we **considered the main sources of uncertainty** by using ***probability density functions*** and ***simplified PDC invasion models***. In particular, we used:

- a **probability map of new vent opening** (*Bevilacqua et al., session 3C*)

- a **probability law describing the distribution of eruptive scales (i.e. PDC invasion areas)** of past events at CF (i.e. we do not need to select a specific reference scenario)

- **simplified PDC invasion models** (*Esposti Ongaro et al., session 3G*)

The final invasion map was obtained by ***Monte Carlo simulation*** by sampling the possible events w.r.t. the above pdf distributions.

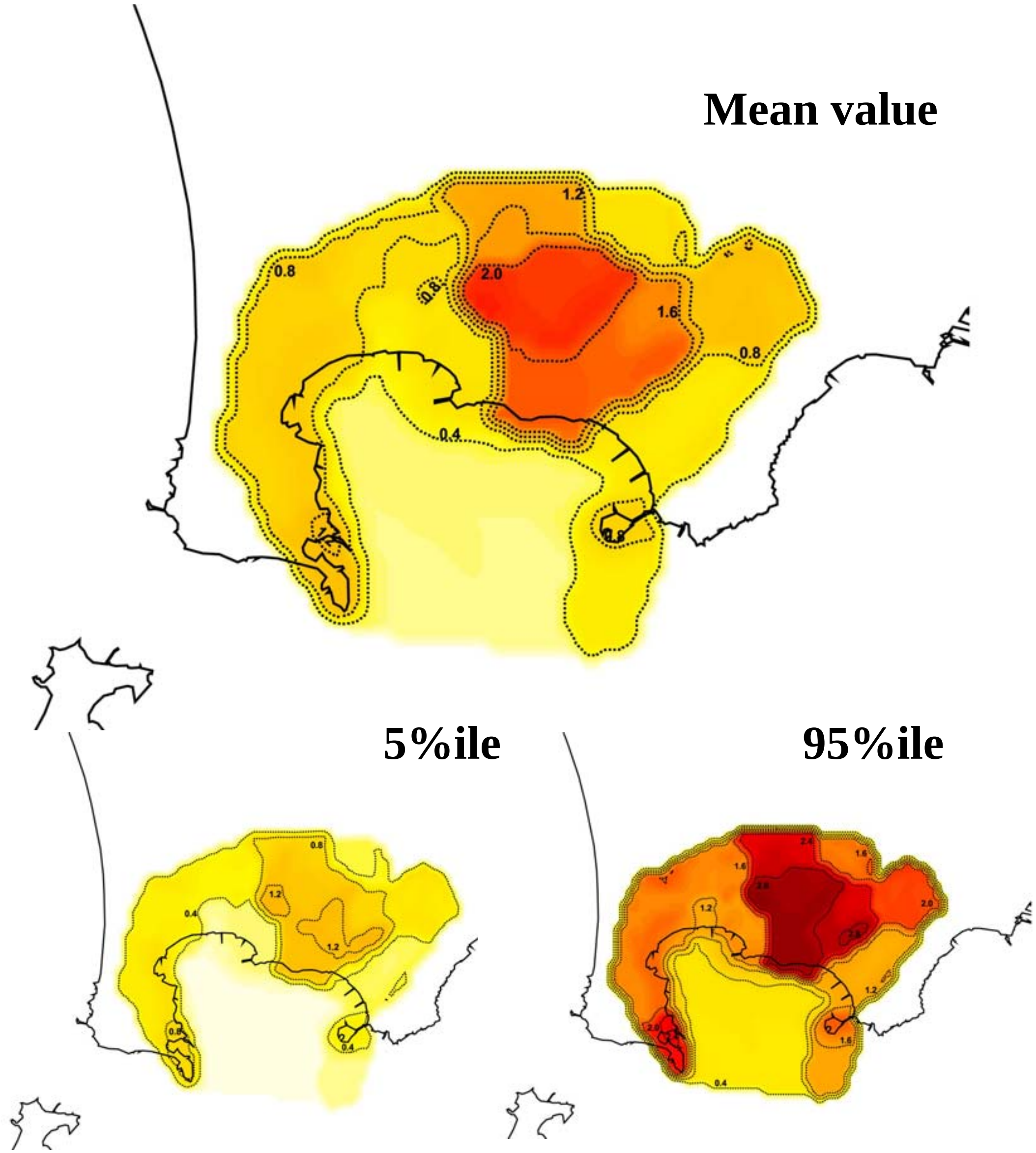
Whenever possible probability distributions were considered together with the ***associated uncertainties***.

Probability map of new vent opening

A first probability map was defined by taking into account the following **volcanological features** of the caldera:

- Spatial distribution of **past vents** (in the last 15 kyr)
- Spatial distribution of **faults**
- Spatial distribution of **fractures**

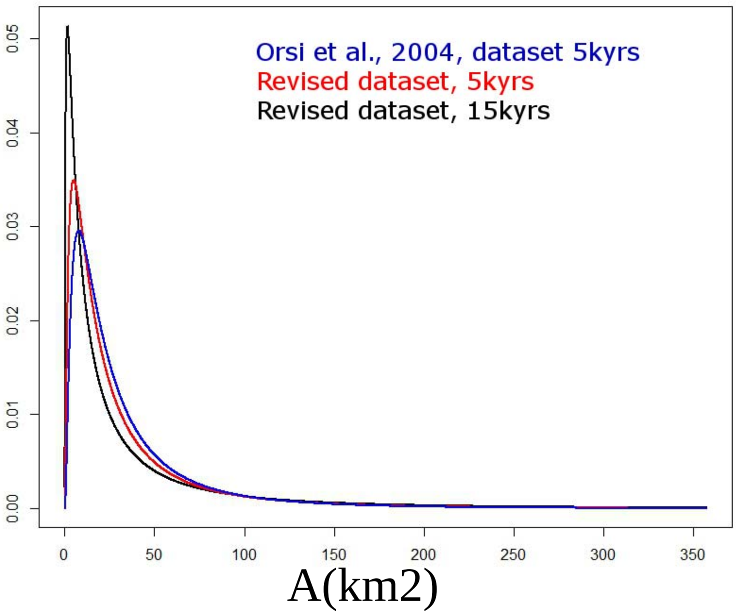
Quantile maps (5 and 95%ile) were obtained by considering the uncertainty on the data through ***mathematical models*** and ***expert judgement*** techniques

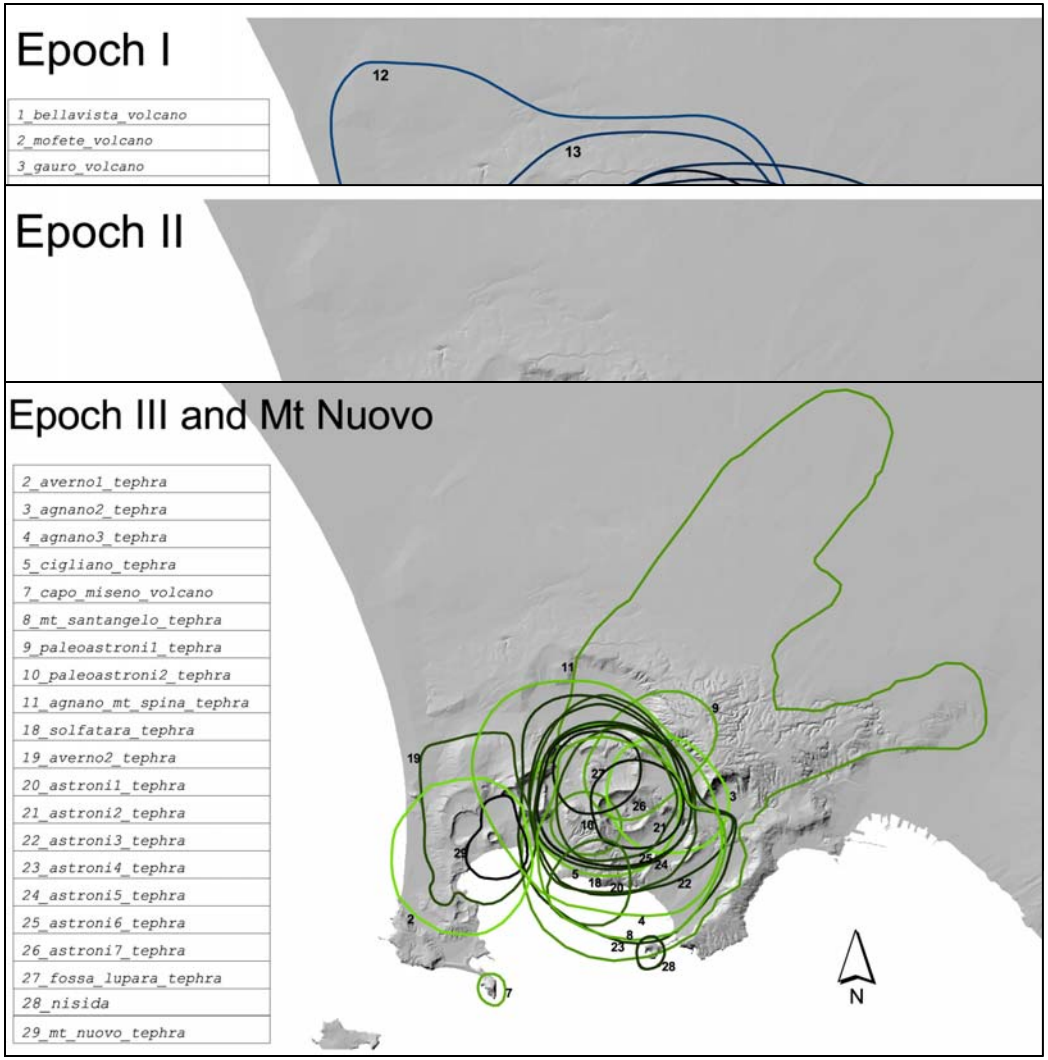


(prob. vent/km2, from Bevilacqua et al., this conf.)

Probability law describing the distribution of PDC invasion areas

- The **distribution of PDC areas** were derived from a revision of the Orsi et al. (2004) dataset.
- Invasion area densities were produced for **different periods** (5 vs 15 kyrs) and **probability density functions** (e.g. lognormal, etc.).





(Revised from Orsi et al., 2004)

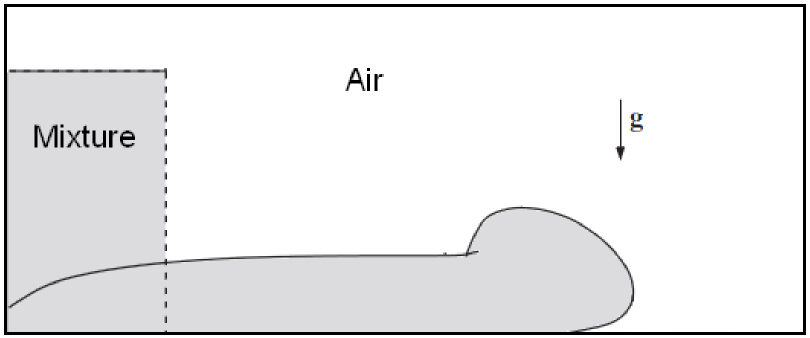
Simplified PDC invasion models

To produce probabilistic invasion maps we implemented a few ***simplified PDC invasion models*** able to describe the ***influence of caldera topography***. In particular:

- **Circular invasion area** model (i.e. actual topographic effects neglected, accounts for an average past topography of the caldera)
- **Energy line** model (*Hsu 1975*) (i.e. energy cone, linear decay of flow energy)
- **Box** model (*Huppert and Simpson 1980, Dade and Huppert 1996*) calibrated by using the **2D multiphase flow model PDAC** (*Neri et al. 2003, Esposti Ongaro et al. 2007*)

The PDC "box model"

The dynamics of the PDC are described as the **collapse of a finite volume of dense fluid in a lighter surrounding atmosphere** and on a flat surface.



Sketch of the lock-exchange configuration

The homogeneous box model gives the **relationship between front velocity and time** as a function of initial conditions, with only one calibration parameter (Froude number experimentally equal to 1.19) (von Karman, 1940)

For **particle-laden currents** (Huppert and Simpson, 1980):

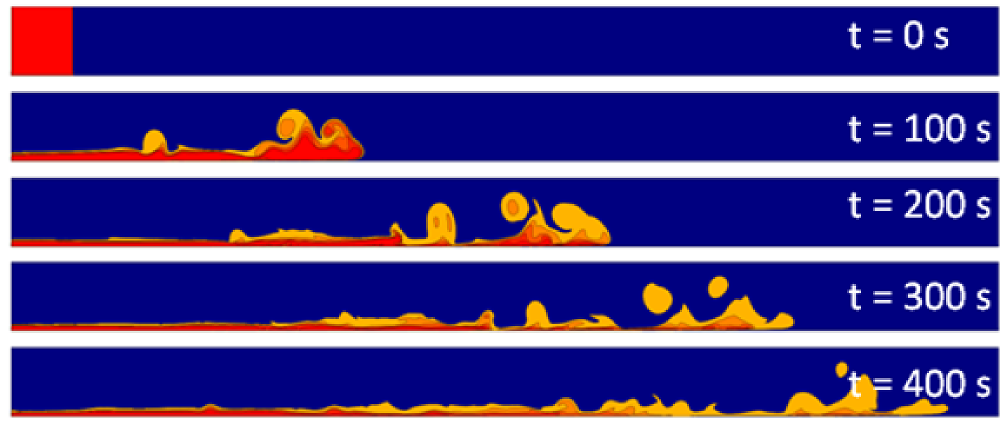
$$\boxed{\frac{\mathrm{d}L}{\mathrm{d}t} = u = \mathrm{Fr}(g'h)^{1/2}}$$

$$\frac{\mathrm{d}\phi}{\mathrm{d}t} = -\frac{V_s\phi}{h}$$

$$g' = \phi g(\rho_p - \rho_a)/\rho_a \equiv \phi g'_p$$

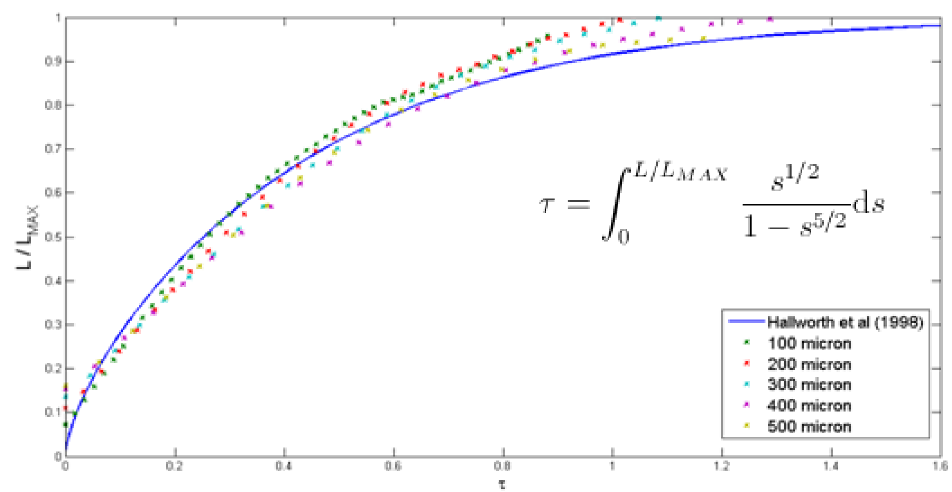
The PDC calibrated box model (1)

Comparisons between the box model results and 2D numerical multiphase flow simulations show **very good agreement in ideal conditions** (fine particles, Boussinesq regime).



Countour of flow denisty at different times (different colors for density current higher from 5% to 50% than atmospheric).
Particle diameter = 10 micron, volume fraction = 5e-4

For ***dense currents, coarse particles, and temperature effects*** the **model still holds** but need to be **calibrated** (e.g. in terms of Fr number, settling velocity, reduced mass due to elutriation)



The PDC calibrated box model (2)

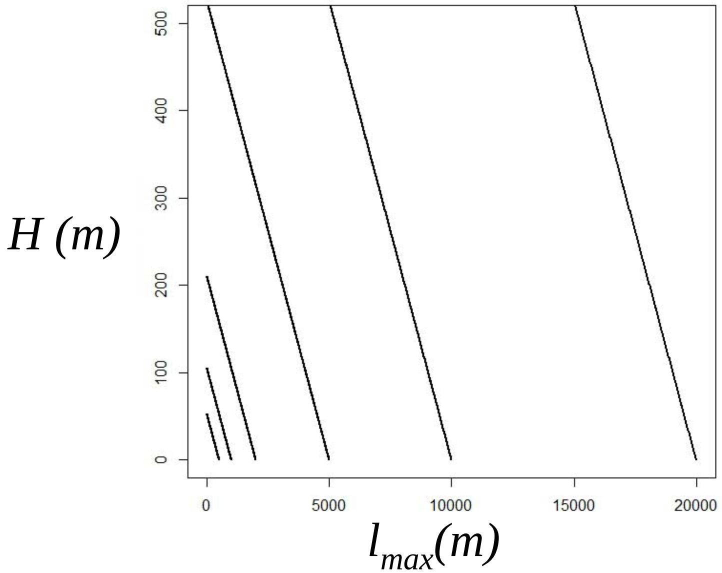
Once the value of l_{max} is known, it is possible to compute the **kinetic energy of the flow front** and therefore the **height of the topographic relief that can be overcome**.

$$x = \frac{l}{l_{max}}$$

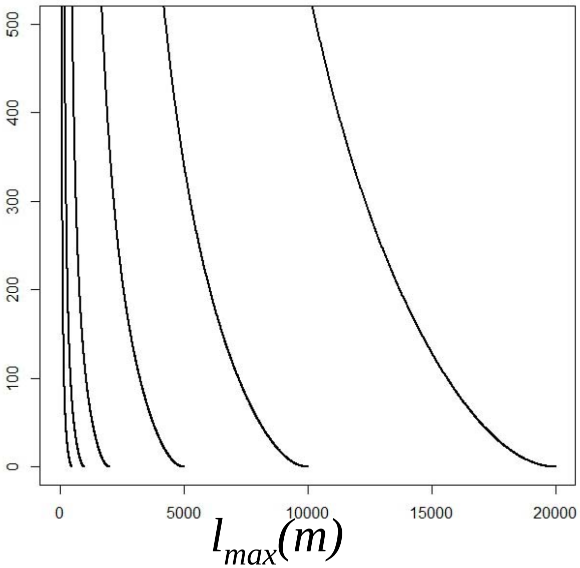
$$H^{(1)}(l, l_{max}) = \frac{1}{2g}\left[\frac{8^{-1/3}C_3 l_{max}^{1/3}}{x\cosh^2 artanh(x^2)}\right]^2$$ (axisym.)

$$C_3 = V_s^{1/3} Fr^{2/3} \phi_0^{1/3} g_p^{1/3}$$

Energy line



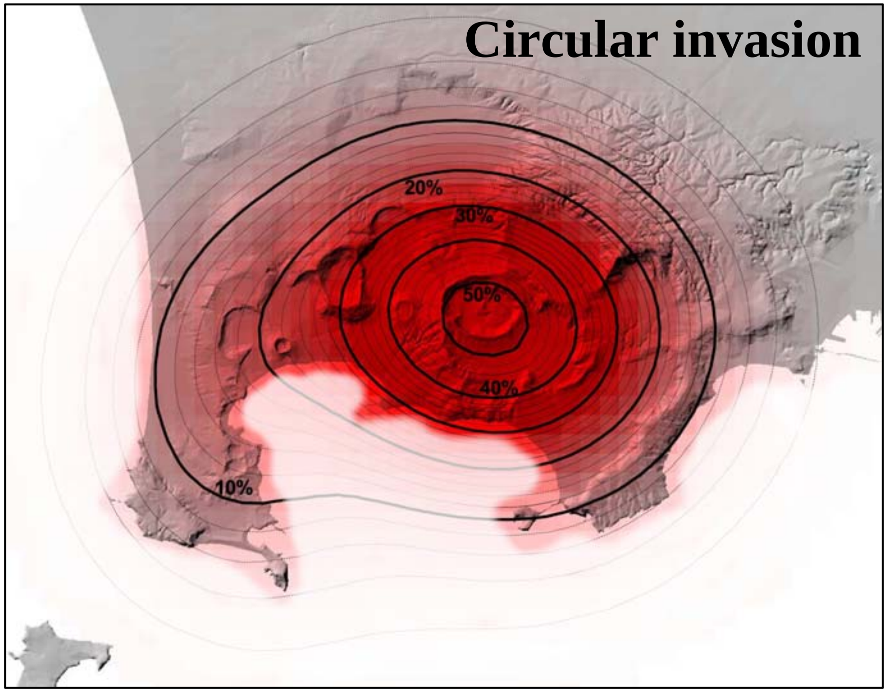
Axisymmetric box model

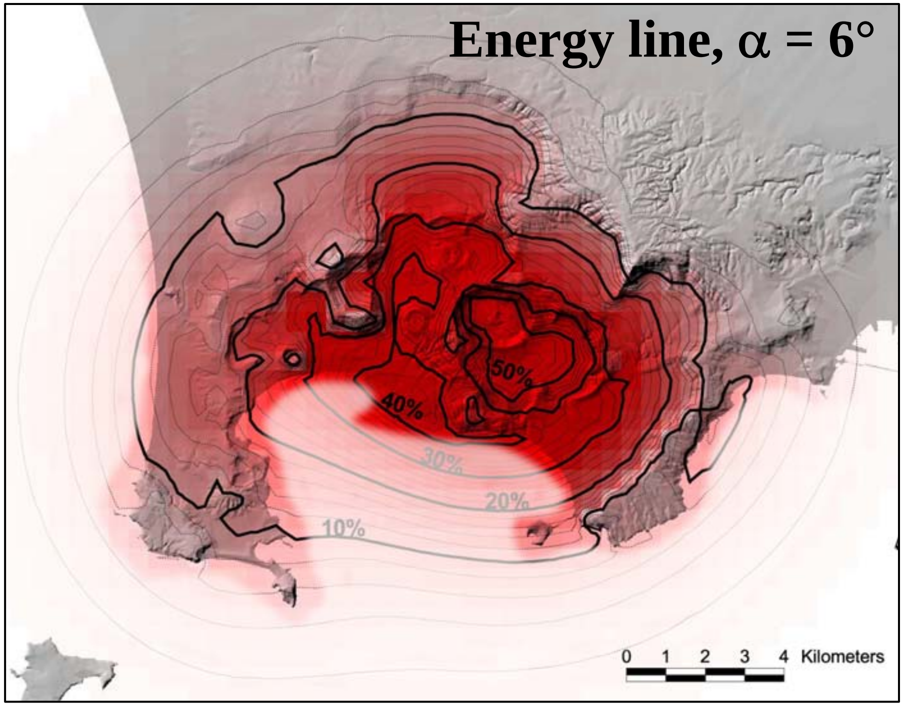


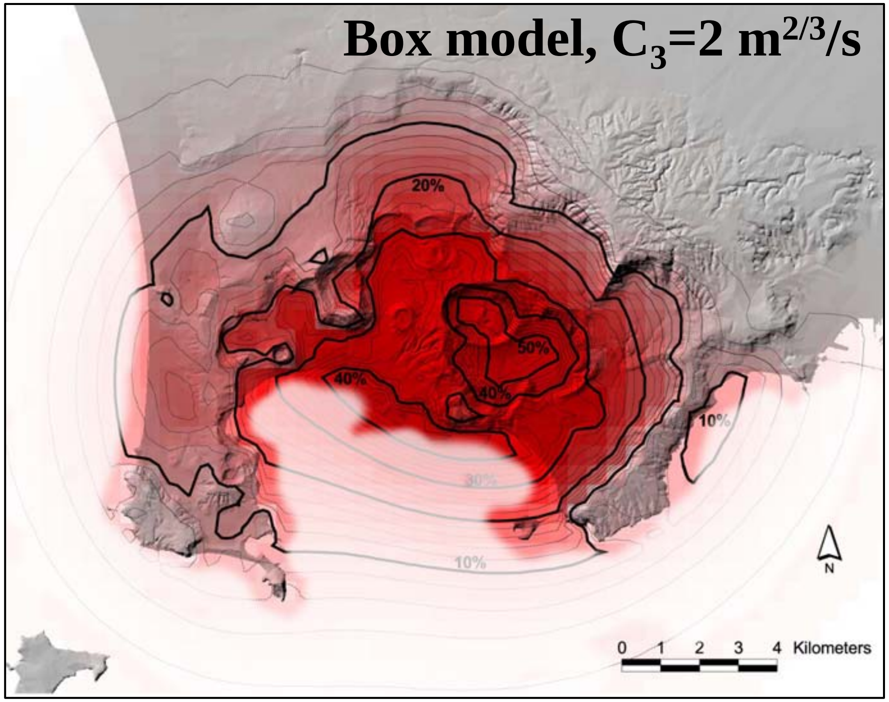
Preliminary probability maps by using the three simplified models

All three maps refer to the **mean probability** values of PDC invasion.

Vent are assumed to open just inland and inside the caldera.



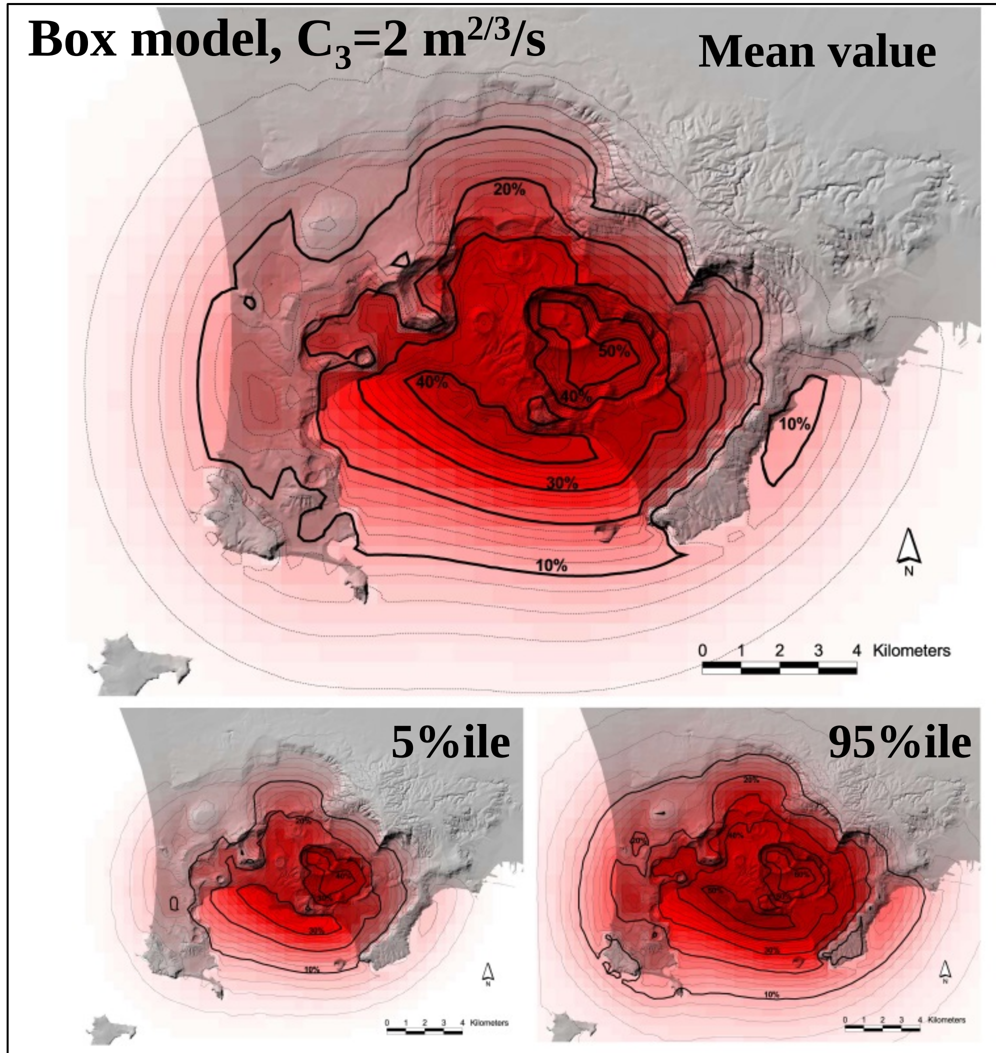




Probability maps by considering the uncertainty on vent locations

The maps represent the **mean and the 5 and 95%ile** considering the **uncertainty on the** probability map of **vent opening.**

The maps were obtained by using the calibrated **box model with C_3 = 2 $m^{2/3}/s$.**



Concluding remarks

- The preliminary results shown represent a **first attempt to quantify** the long-term PDC hazard at CF.
- The hazard maps explicitely consider the **two main unknowns** of the system, i.e. the **vent location** and the **eruption scale**.
- All three maps produced appears to **capture the first-order features** of the probability of invasion. Main differences are shown along the **caldera rims** where the topographic effect is captured by the **energy line and the calibrated box model**.
- The uncertainty on the probability of **vent location** appears to have a **large effect** on the invasion map.
- Further progress appears to be linked to the use of PDC models able to describe the **3D features of the caldera** and to a better **quantification of the uncertainty sources**.

Acknowlegments

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