FROM FIELD DATA TO NUMERICAL MODELS: APPLICATION OF THE BOX-MODEL TO INFER THE DYNAMICS OF PDC GENERATED DURING THE AD 79 ERUPTION OF SOMMA-VESUVIO

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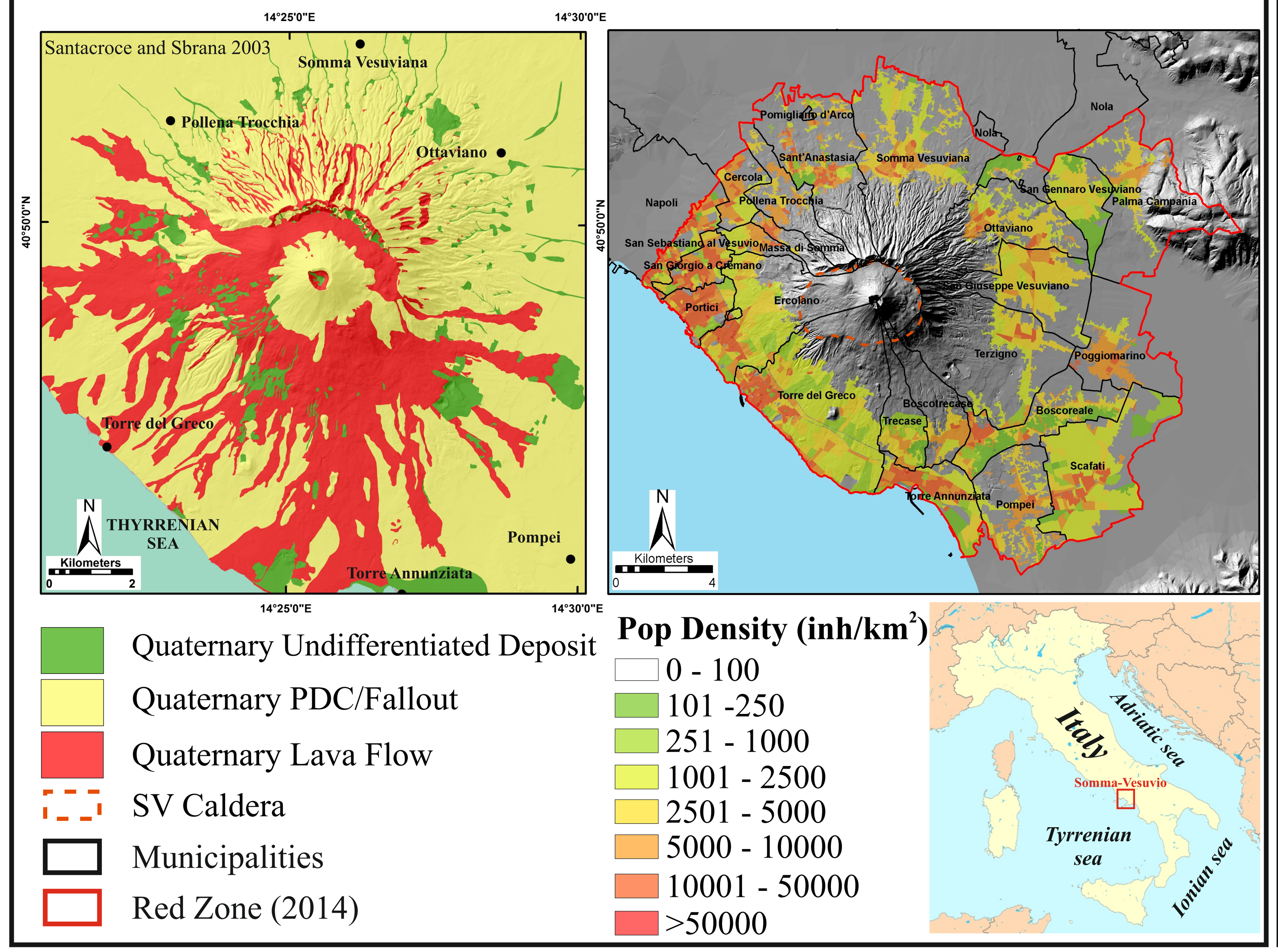
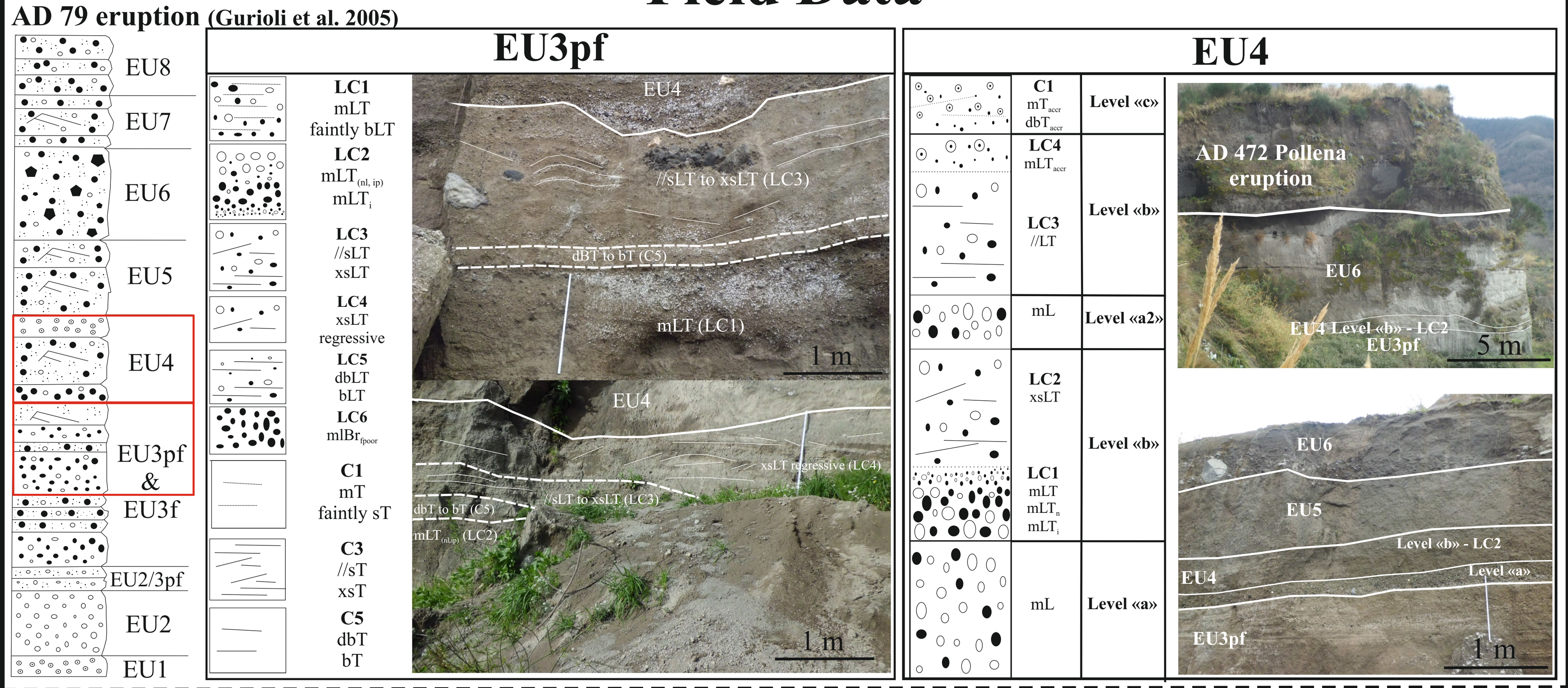
Abstract

The purpose of this work is to present a validation procedure in the physical and numerical modeling of Pyroclastic Density Currents (PDC), using feedbacks from well-known deposits emplaced by specific single eruptive units. The study is specifically focused on the PDCs generated during the famous AD 79 eruption of the Somma-Vesuvio volcano. Values of the maximum runout, volumes and Total Grain Size Distributions (TGSD) have been estimated for two eruptive units (i.e. EU3pf and EU4) of that eruption. These input volcanological parameters have been used for testing the Box-Model of Dade and Huppert (1995) hind-casting performance. We focus on one specific end-member of the complex spectrum of PDCs, that is the more dilute, turbulent part of them, i.e. stratified flows with concentration of solid particles in volume up to about 5%. The Box-Model is a kinematic approach, which calculates the average flow density and flow front velocity along time. The corresponding kinetic energy can be compared with the potential energy needed to overcome topographic obstacles, so to estimate flow invasion across complex topographies. Validation of the model against the field data has been performed with respect to: i) the degree of overlapping between inundation areas (model output/deposit); ii) the thicknesses of model output/deposit with distance from vent area; iii) the mass fractions of the different grain size classes of model output/deposit with distance from vent area. Several simulations have been performed assuming i) polydisperse (with 10 grain size classes) and monodisperse (with the Mdφ values) systems; ii) a direct implementation (where the initial volume is released and the invasion area is computed) and an inverse implementation (where the initial collapsing volume is a function of an inundation area defined by the user); iii) axisymmetrical and directional collapses. Results enable us to obtain first order estimates of the main variables at the flow source and emplacement. Among the two eruptive units chosen for model validation, the EU4 one provided better results after empirical calibration of settling velocity and initial volume fraction of solid particles, indicating that the Box Model can be suited to represent the kinematics of large (volume > ~10^8 m^3, runout > ~15 km) PDC at Somma-Vesuvio.

Somma-Vesuvio area



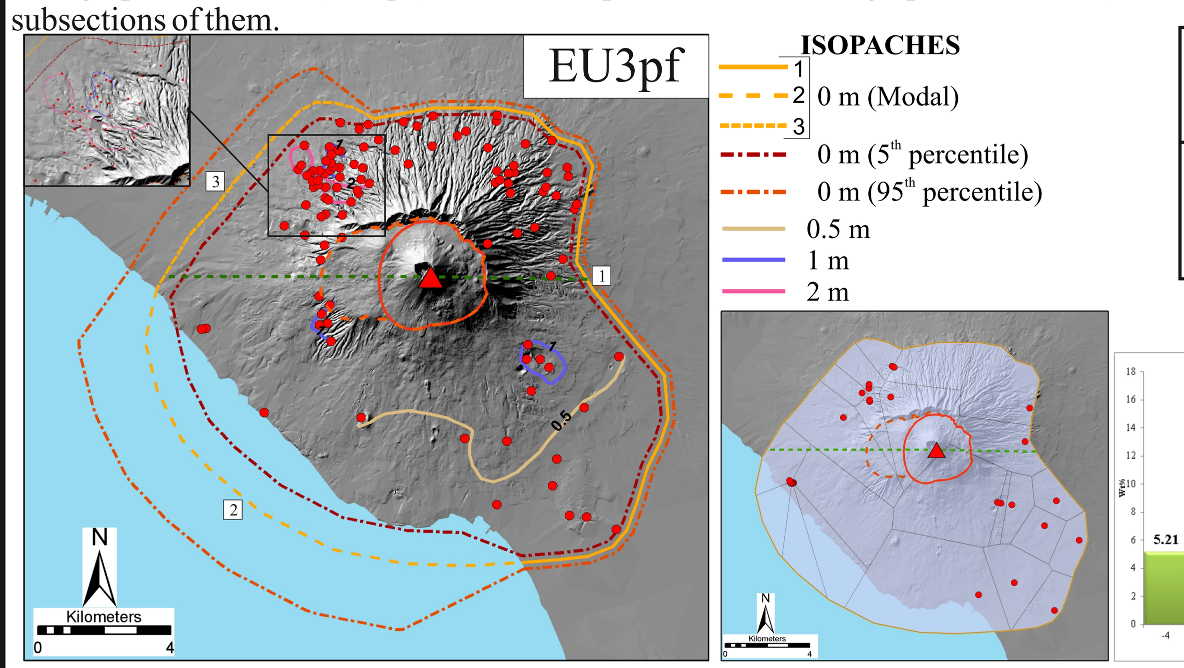
Field Data



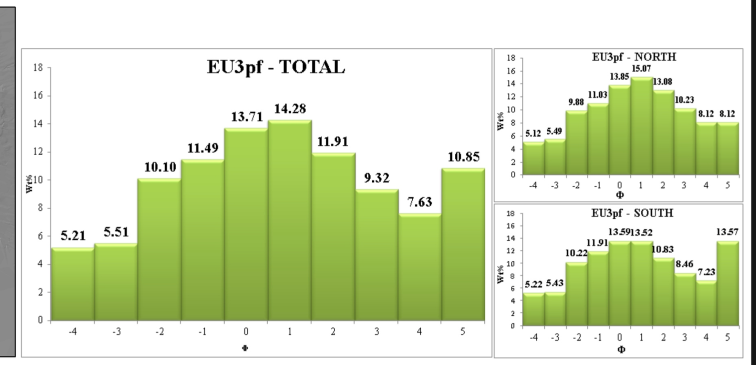
Maximum Runout estimations have been performed by reconstructing the ideal PDC 0 m isopach (farthest limit of the features typical of lateral transport). Three different outlines of PDC maximum runouts are presented for each unit (Modal, 5th percentile and 95th percentile - representing uncertainty). Modal maximum runout outline is composed by different segments with different degrees of confidence: for each the percentiles lines have been traced following specific evaluations.

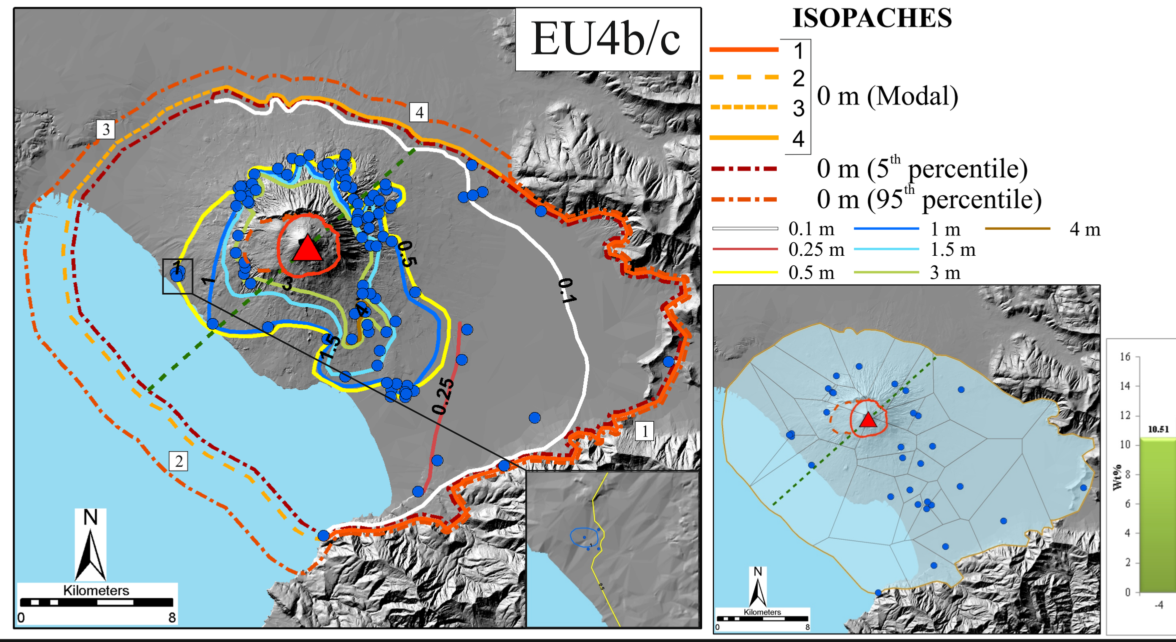
Volume estimations have been performed using a TIN (Triangular Irregulated Network) linear interpolation. We have considered both the whole units and some subsections of them (N-S for EU3pf and NW-SE for EU4b/c). Number of stratigraphic sections employed: 106 for EU3pf, 102 for EU4b/c

TGSD estimations have been performed using a Voronoi tessellation approach (Bonadonna and Houghton 2005) using 98 samples from 27 stratigraphic sections (EU3pf) and 68 samples from 31 stratigraphic sections (EU4b/c). Estimations for both the whole units and subsections of them.

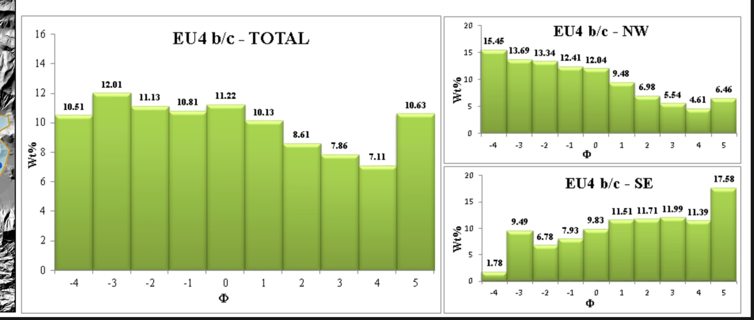


Sector	Volume (km³) 5th-Modal-95th
TOTAL	**0.152-0.188-0.240**
NORTH	0.080-0.096-0.113
SOUTH	0.072-0.092-0.127





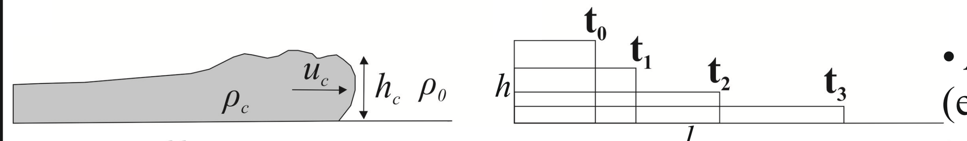
Sector	Volume (km³) 5th-Modal-95th
TOTAL	**0.303-0.306-0.325**
NW	0.120-0.121-0.134
SE	0.183-0.185-0.195



Numerical Modeling

Box Model

Dade and Huppert (1995): Bevilacqua (2016); Esposti Ongaro et al. (2016)



$$\begin{cases} u = \dfrac{dl}{dt} = Fr(g_p \Phi h)^{1/2} & \textbf{Conservation of momentum} \\ l^2 h = V & \textbf{Conservation of mass} \\ \dfrac{d\Phi}{dt} = -\sum_{i\ 1}^{n} \dfrac{w_{si}\Phi_i}{h} & \textbf{Particle sedimentation} \end{cases}$$

- Advanced version of the classical kinematic approach (e.g. Energy cone)
- The conservation of mass is obtained through equal area geometrical elements that stretch out through time
- Comparison between the topography and the decay of kinetic energy with distance («Energy conoid»)
- Capable of reproducing PDCs with volume fraction of solid particles from 0.5% to 5-6%

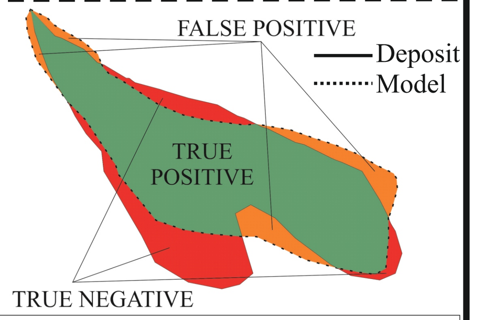
- Polydisperse (using 10 grain sizes) and Monodisperse (using Md_φ values) simulations
- Axisymmetrical and directional simulations
- Direct (from initial volume to inundation area) and inverse (from inundation area to initial volume) version of the Box-Model
- Sensitive parameters: initial volumetric content of solid particles (φ_0) and settling velocities of solid particles (w_s). For w_s, formulae by Doyle et al. (2010) and Esposti Ongaro et al. (2016)
- Employment of a DEM with a reconstructed paleotopography prior to AD 79 eruption

Validation procedure

With respect to inundation areas of model versus deposit (True Positive, True Negative, False Positive)

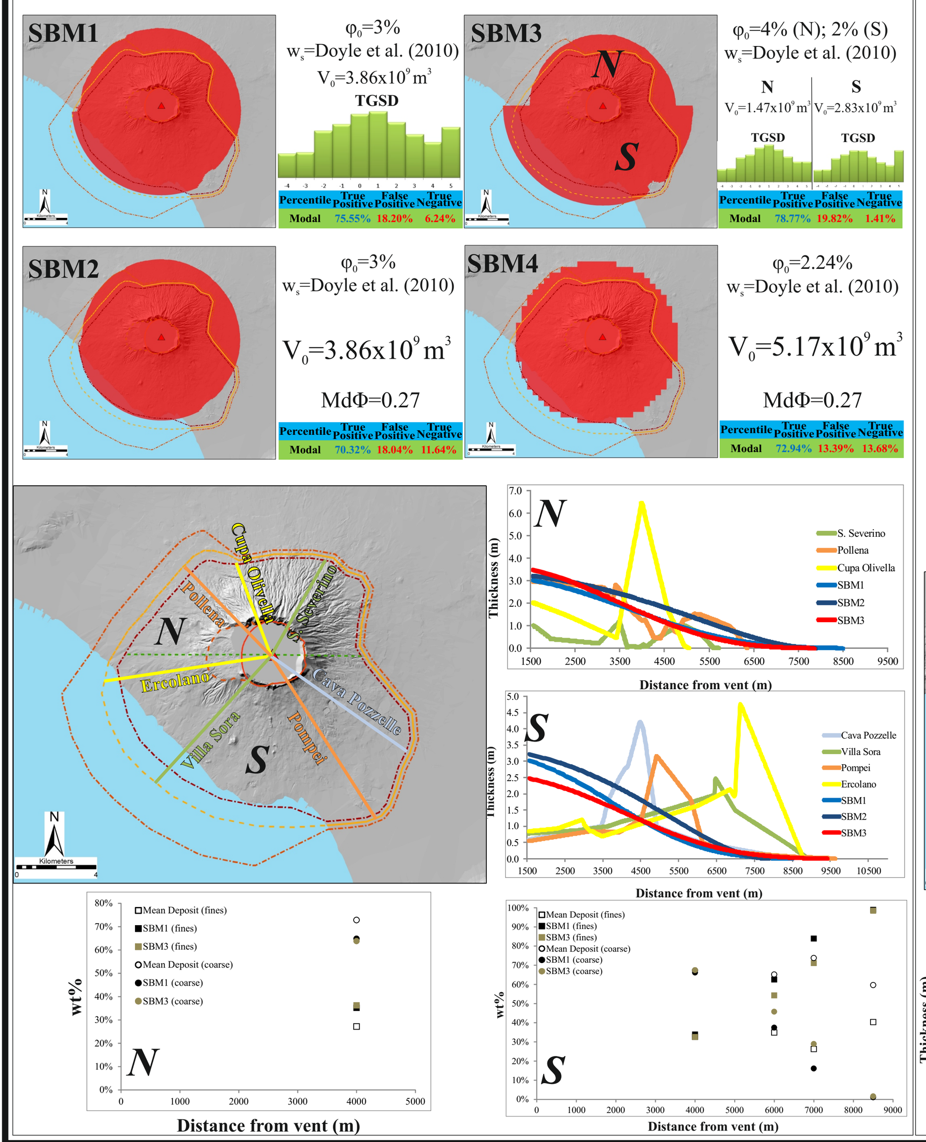
With respect to thickness of the model versus thickness of the deposit with distance from vent area

With respect to mass fraction of different grain sizes of model and deposit with distance from vent area



EU3pf

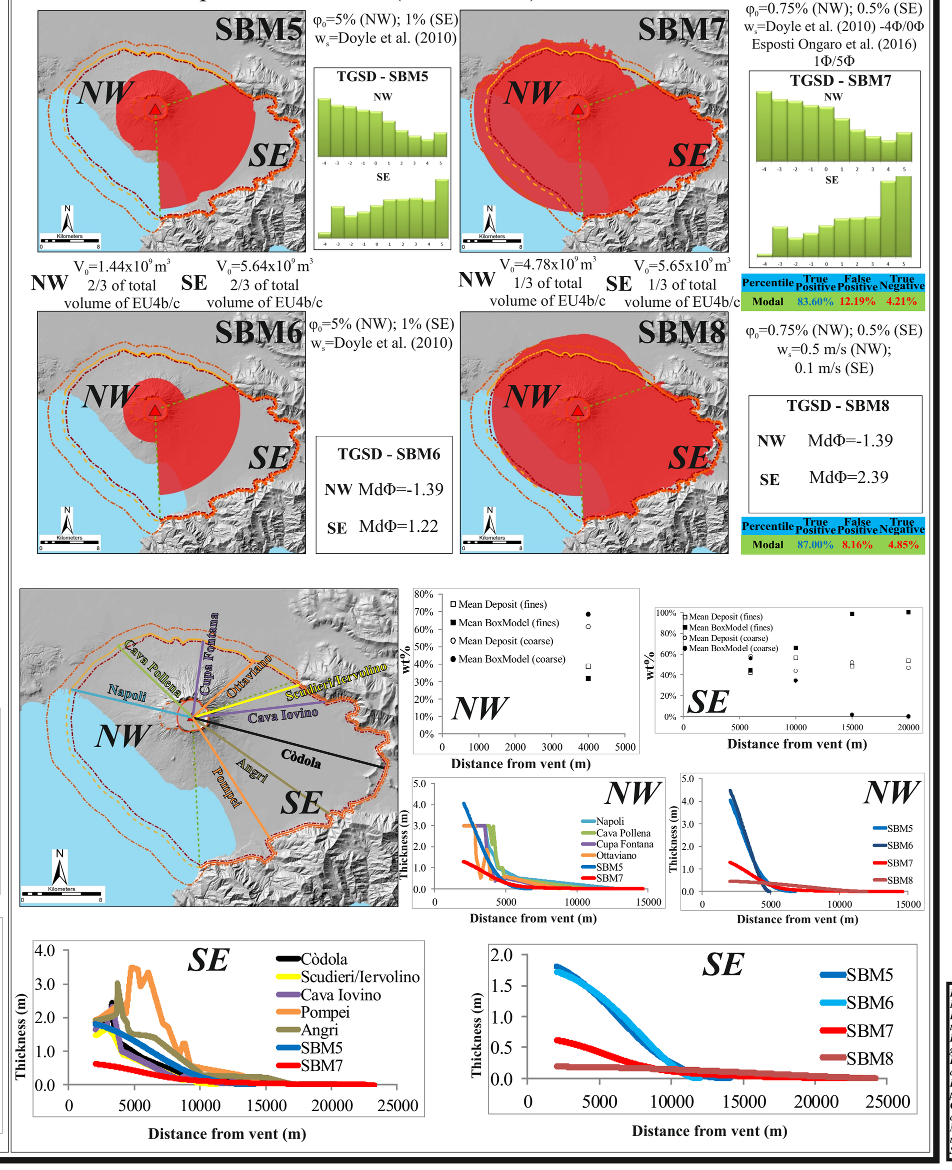
SBM1: polydisperse, axisymmetrical, direct.
SBM2: monodisperse, axisymmetrical, direct.
SBM3: polydisperse, directional (N and S), direct.
SBM4: monodisperse, axisymmetrical, inverse.



EU4b/c

SBM5: polydisperse, directional (NW and SE), direct.
SBM6: monodisperse, directional (NW and SE), direct.
SBM7: polydisperse, directional (NW and SE), direct.
SBM8: monodisperse, directional (NW and SE), direct.

SBM7 and SBM8: +15% volume added (equally distributed in the 4Φ and 5Φ grain sizes).



Concluding Remarks

- Estimation of physical parameters (max runout, TGSD and Volume) for two Eruptive Units (EU3pf and EU4) from the AD 79 Plinian eruption
- Validation of the Box-Model using field data
- Introduction of a new validation procedure based on three comparisons (with respect to inundation area, thickness with distance and mass fraction of different grain sizes with distance) between the output of the model and the real deposit
- Proof of stronger reliability of the Box-Model code for the reproduction of the more dilute part of PDCs
- Identification of the input parameters (TGSD, φ_0 and w_s) which influence the most the final output of the model.

Future Work

- Collection of more field data for the studied units; comparison with different methods for field data calculation
- Calculation of the amount of material not deposited by the Box-Model
- Implementation of a PDC probabilistic invasion map (using the Box-Model) for the SV area which takes into account the results of this validation (like at Campi Flegrei - see Neri et al. 2015).

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Acknowledgments

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