GIS BASED TOOL FOR VOLCANIC HAZARD ASSESMENT AND SUPPORT DECISION

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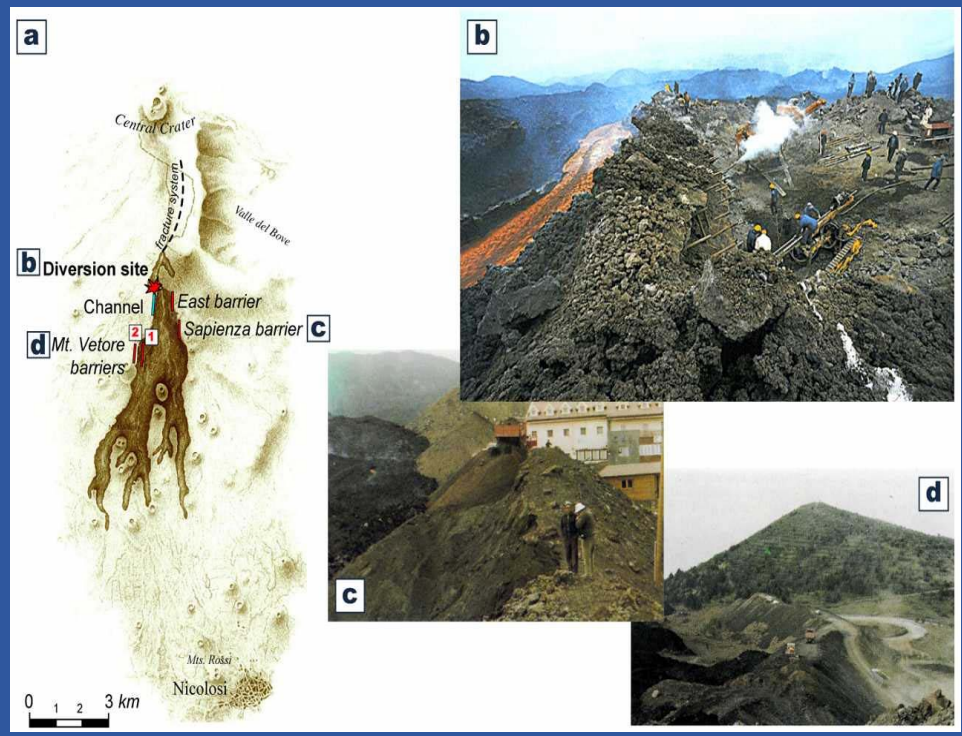
Introduction

Etna activity :
- effusive activity
- one eruption every year / 2 years
- eruption duration from 1 week to 6 month
- important damage to infrastructures

Etna zone :
- 1 million inhabitants
- growing urbanization



(Barberi and Carapezza, 2004)

Outlines

Modeling and simulating lava flows emplacement on effusive volcano such as Mt Etna.

- Long term forecasting of the flow direction to follow the progress of an event.
- The verification of the possible effects of human intervention.
- Production of hazard maps.

Simulation time << eruption duration

Modeling of a lava flow

A lava flow is :

→ a 3D flow

→ with free surface

→ of complex fluid

→ with thermal exchanges

} Coupled, non-linear PDE system

Critical parameters :

→ effusion rate

→ topography

→ rheology

Numerical approaches

Numerical solution of equations :

→ finite elements

→ finite differences

→ meshfree methods

} At present time not compatible with the condition : simulation time << eruption duration

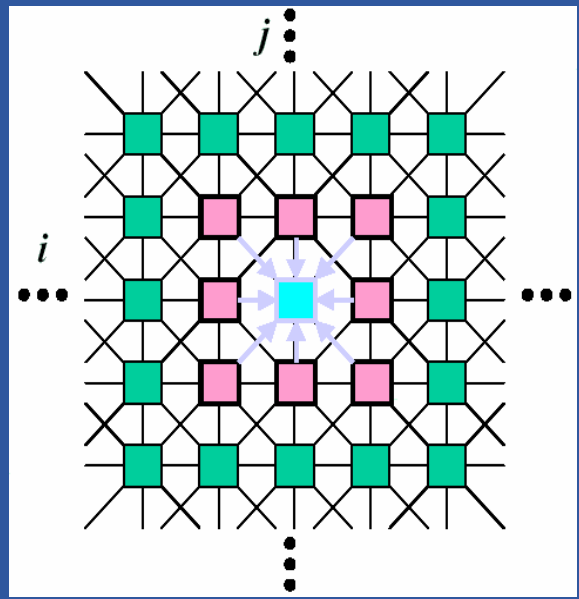
Reproduction of system behaviors :

→ cellular automata

Cellular automata

Key concepts :

→ neighborhood
→ parallelism
→ determinism
→ homogeneity
→ discretization



Technical characteristics :

→ dimension
→ state variables space
→ neighborhood type
→ evolution function

CA model for lava flows : Magflow

- For each cell we define two state variables: thickness of lava and quantity of heat.
- The evolution function of CA is a steady state solution in of Navier-Stokes equation for the motion of a Binghamian fluid on a inclined plane subject to pressure force.

This kind of method induces a strong dependence from the cell geometry and position of the flux, respect to the symmetry axis of the cell. It is possible to solve this "systemic anisotropy" effect by a Monte Carlo approach.

GIS integration

Since :
- the input topography is accessible trough a GIS
- the effusion rate can be estimated trough infrared satellite images processed in a GIS
- MAGFLOW produce forecasting and hazard maps
- MAGFLOW should be usable in autonomous way from local authorities and the Civil Protection

We fully integrated the MAGFLOW model as a module of GRASS GIS.

GIS integration

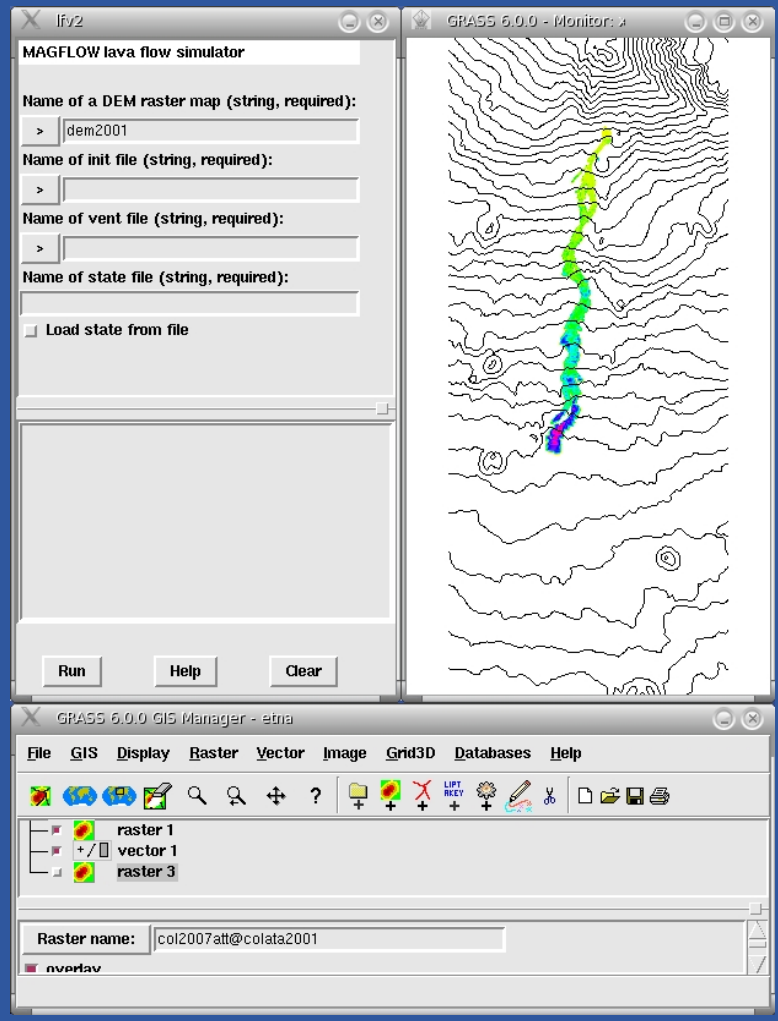
IR satellite images

effusion rate

cartographic database

MAGFLOW

visualisation

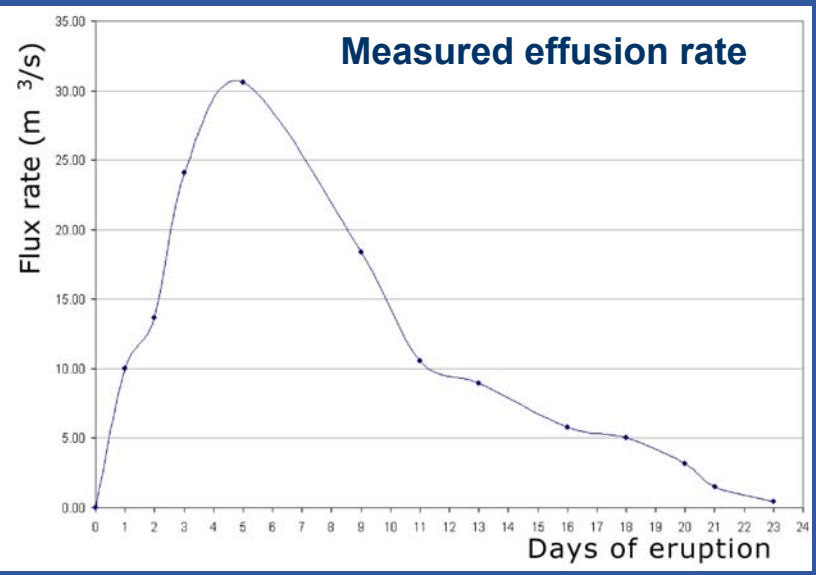


Application : flow forecasting

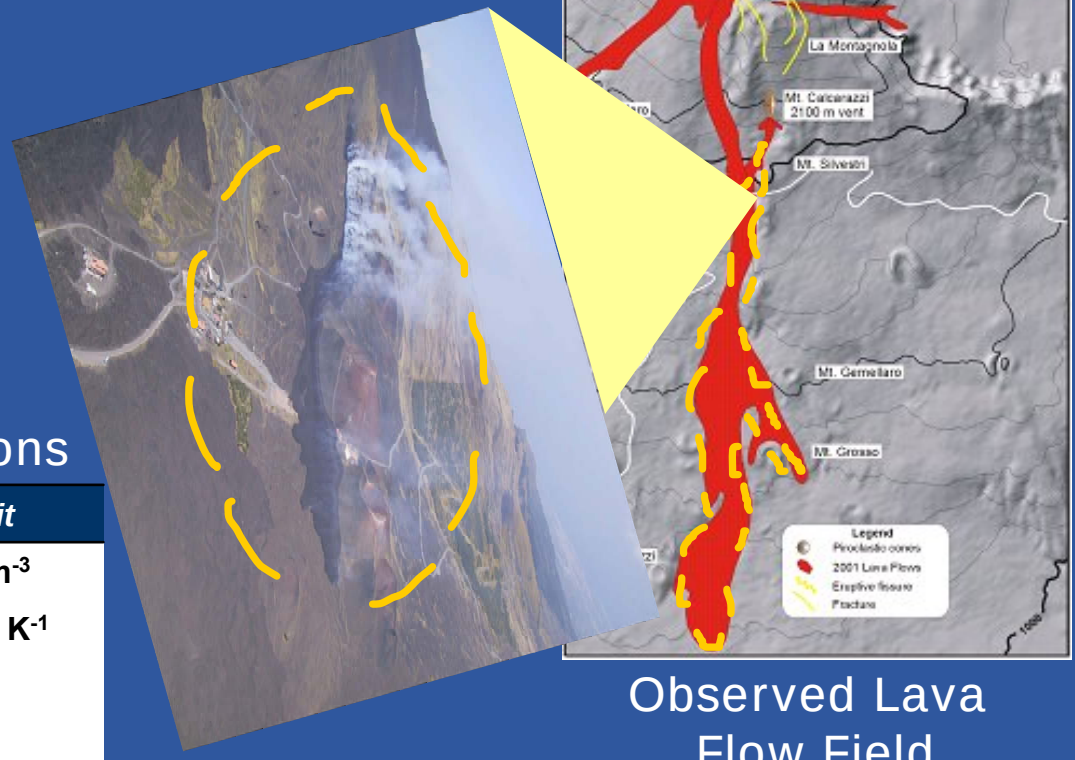
The 2001 Etna eruption provided the opportunity to verify the ability of MAGFLOW model to simulate the path of lava flow and to calibrate some parameters involved in the simulations.

During the 2004 and 2006 Etna eruption, MAGFLOW code allowed us the production of real-time simulations as changing of eruptive parameters.

2001 Etna eruption



Vent = (501800, 4173400)
Eruption = 22 days
DEM resolution = 10 m



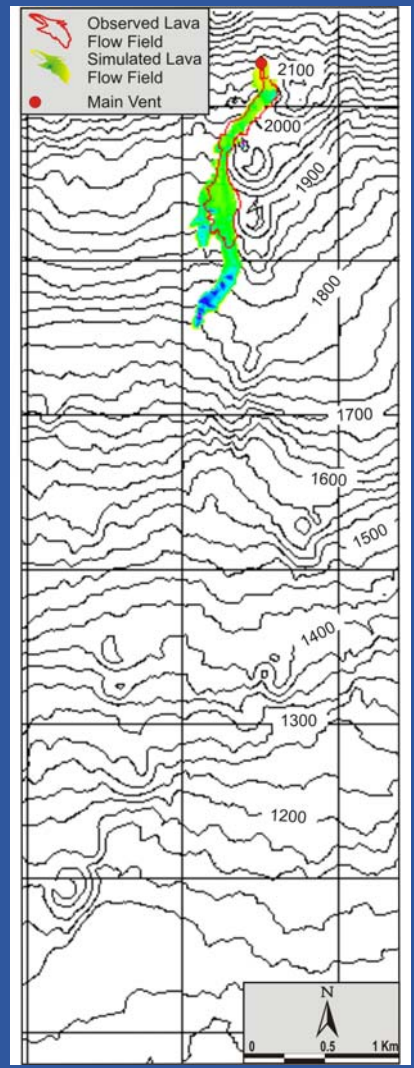
Observed Lava Flow Field

Parameters used for the simulations

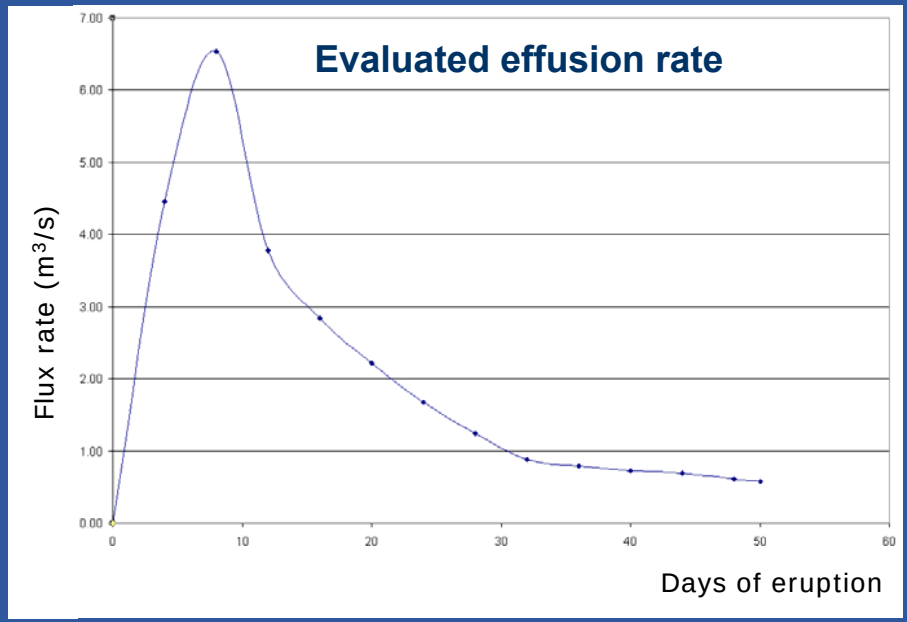
Parameter	*Value*	*Unit*
density (ρ)	2700	kg m^{-3}
specific heat (c_p)	1150	J kg^{-1} K^{-1}
emissivity (ε)	0.9	
T solidification	1173	K
T extrusion	1360	K

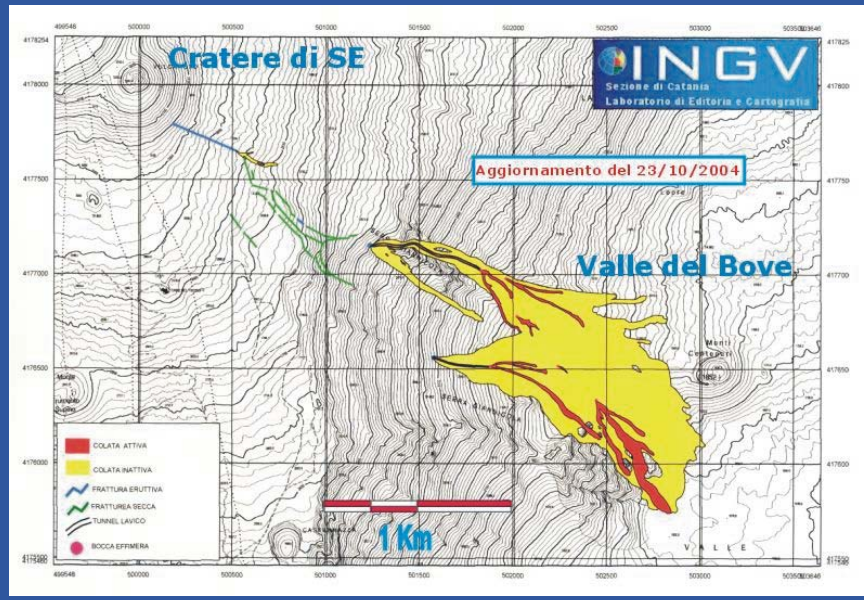
Temporal evolution of 2001 Etna eruption

Observed data furnished by Coltelli (INGV-CT) and Marsella (University of Roma).



2004 Etna eruption





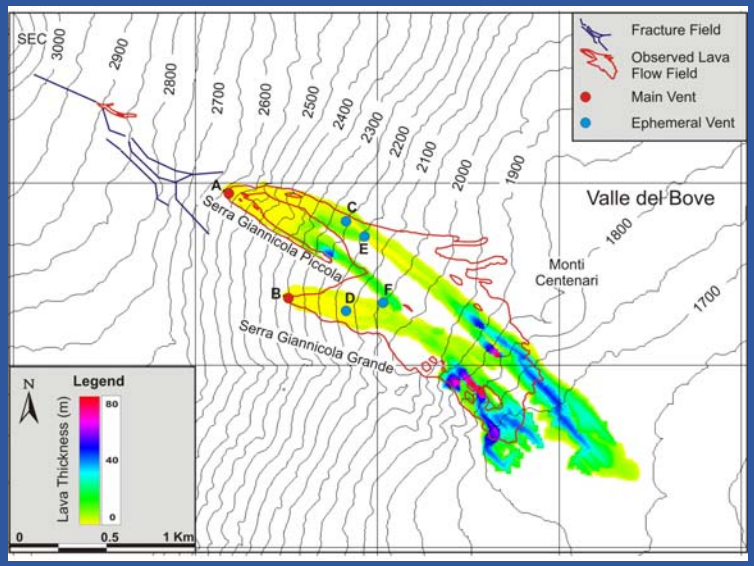
Observed Lava Flow Field

Eruption = 43 days
DEM resolution = 10 m

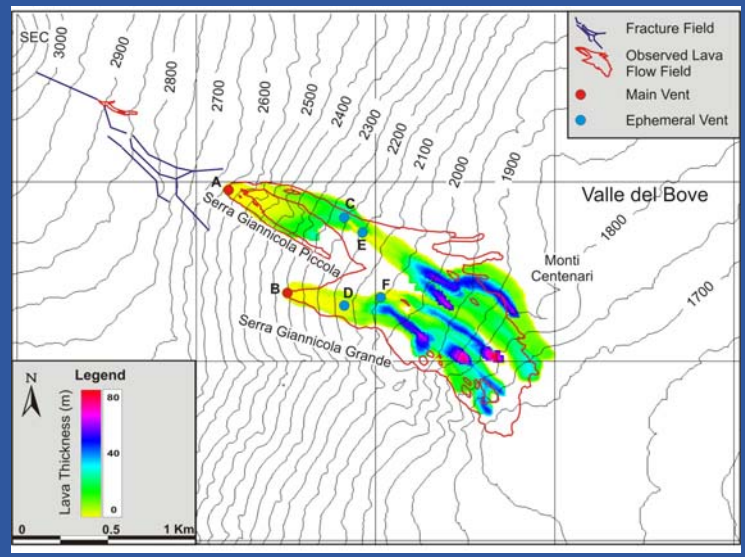
Parameters used for the simulations

Parameter	*Value*	*Unit*
density (ρ)	2700	kg m^{-3}
specific heat (c_p)	1150	J kg^{-1} K^{-1}
emissivity (ε)	0.9	
T solidification	1173	K
T extrusion	1360	K

2004 Etna eruption

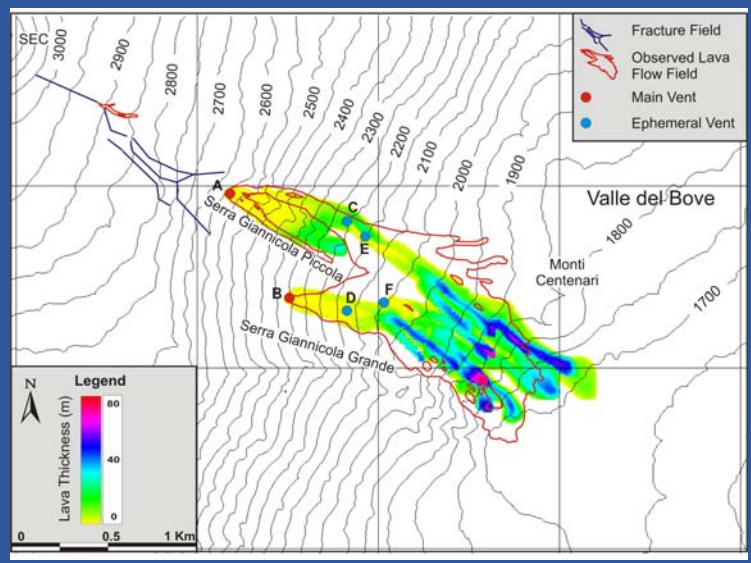


Giordano and Dingwell, 2003



Ishiara et al., 1998

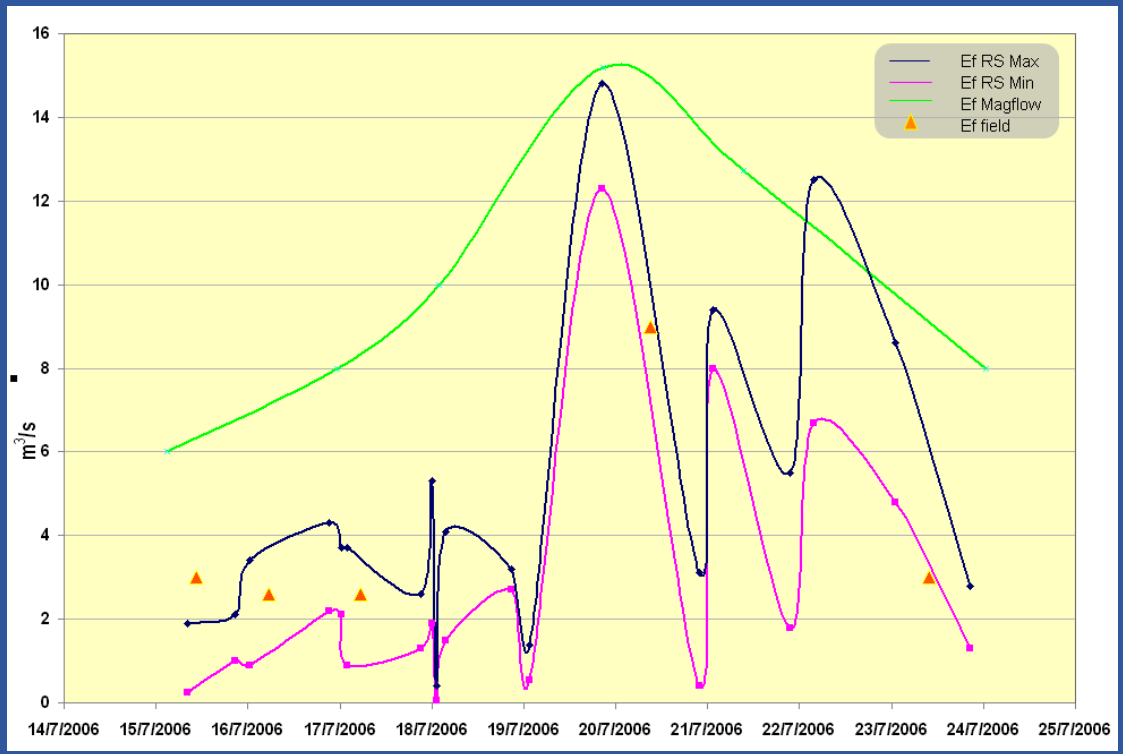
A = (501159; 4176958) z=2620 m
B = (501489; 4176382) z=2320 m
C = (501828; 4176804) z=2220 m
D = (501828; 4176314) z=2130 m
E = (501928; 4176719) z=2150 m
F = (502028; 4176355) z=2050 m



Pinkerton and Norton, 1995

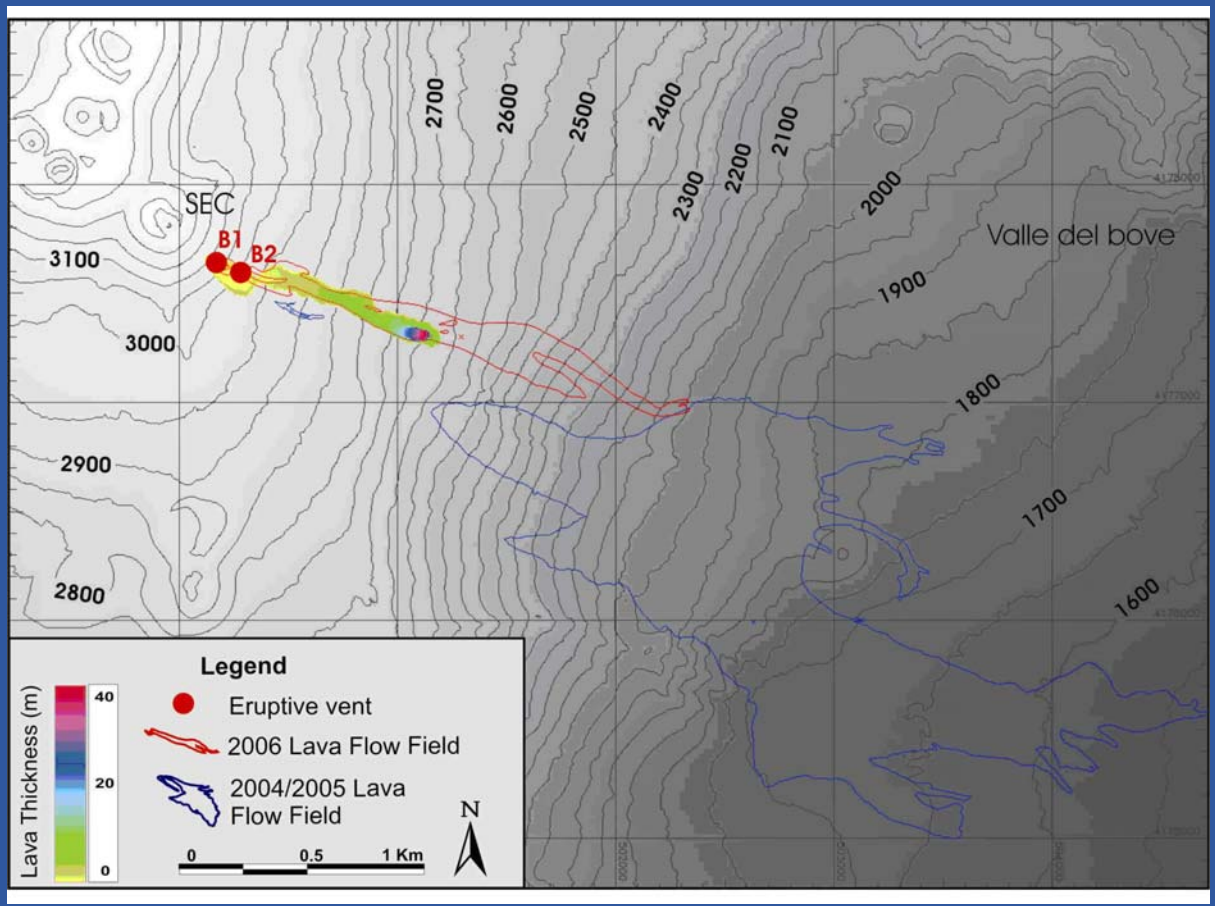
2006 Etna eruption

Flow rate



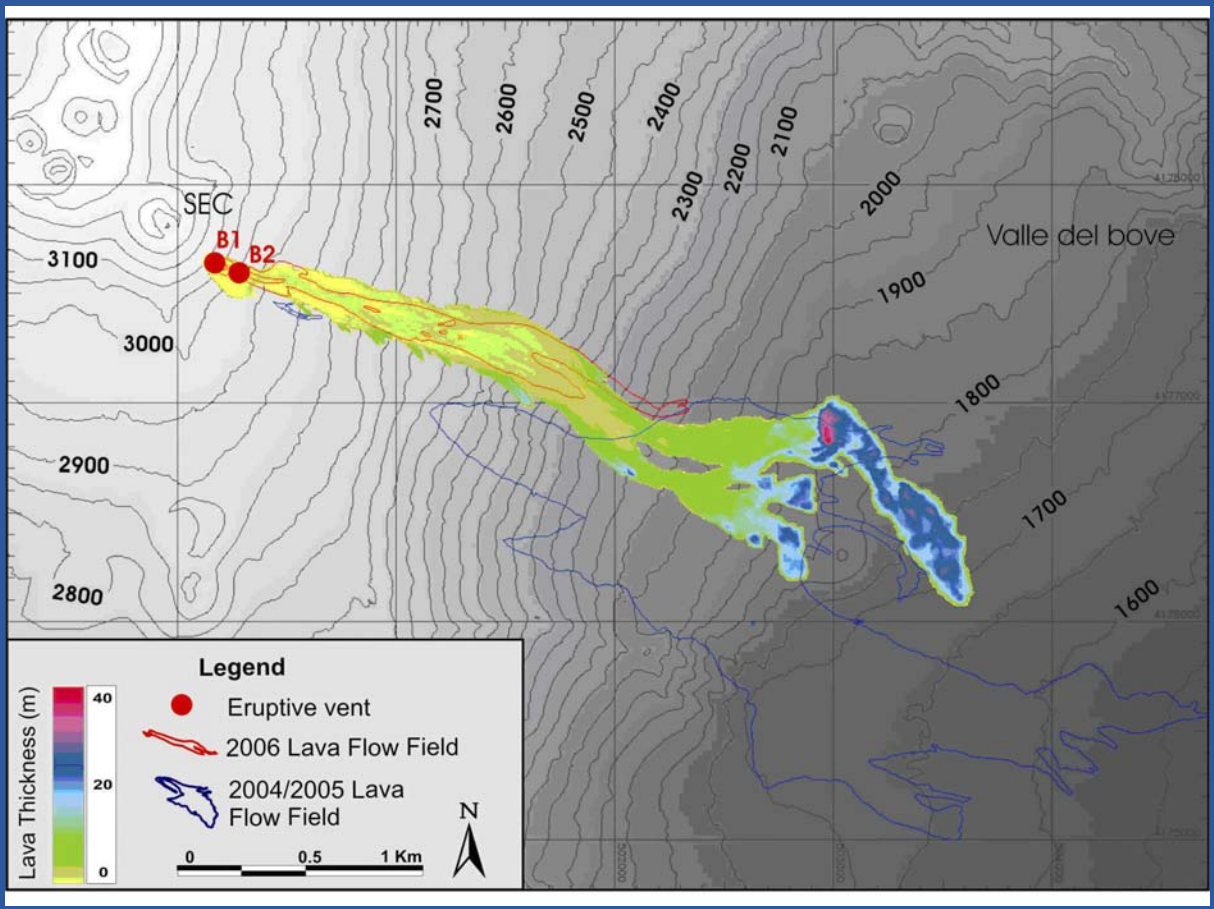
- Pink curve : minimum value measured by remote sensing (IR satellite imaging)
- Blue curve : maximum value measured by remote sensing (IR satellite imaging)
- Yellow triangle : field measurement
- Green curve : flow rate used in simulation when no other information was available

2006 Etna eruption



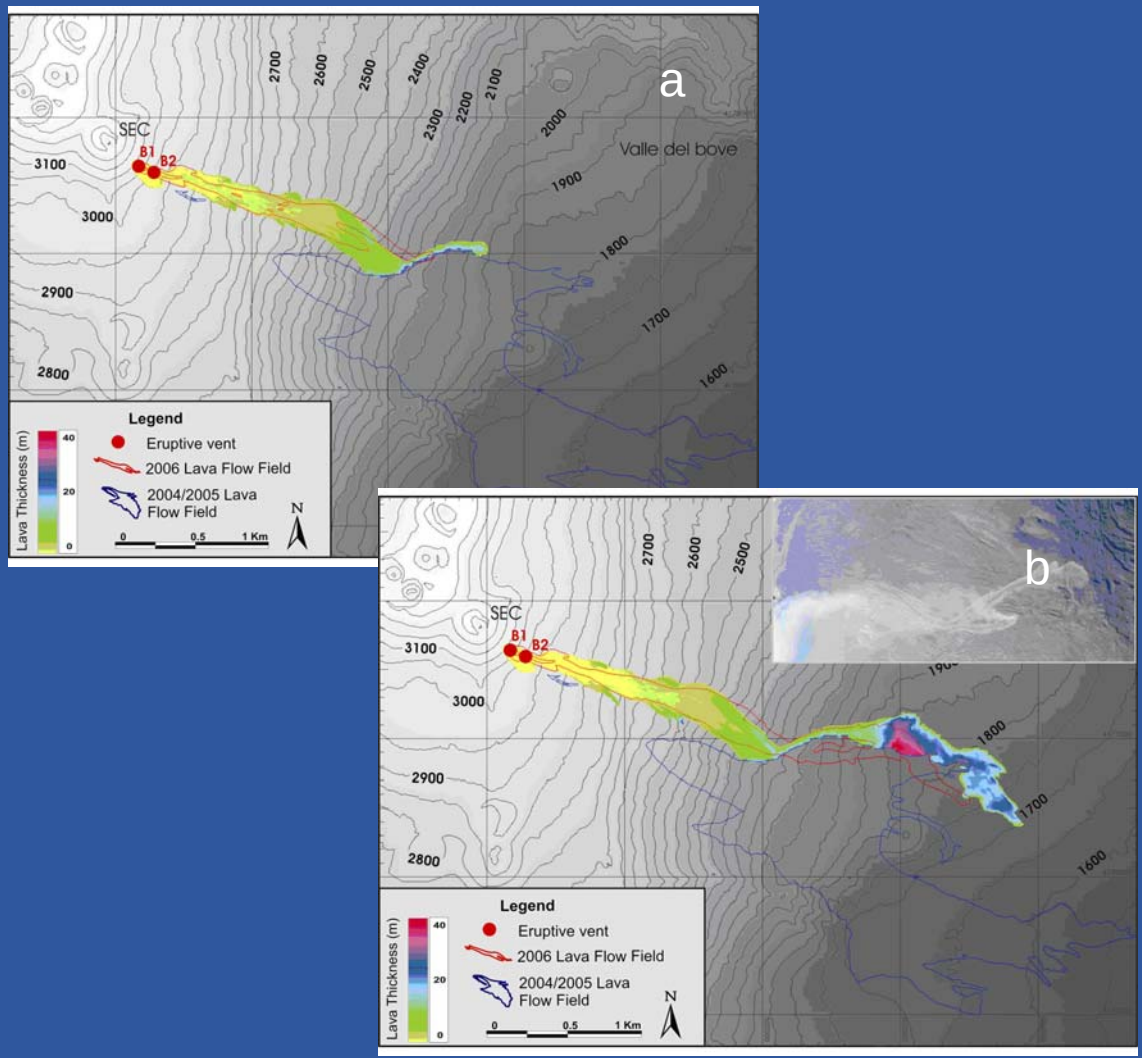
Simulated scenario of the 17 July 2006 computed using an average value of effusion rate of 2.6 m^3/s (1.3 m^3/s for each vent). The red contour is the real map of lava flow updated to 17 July 2006.

2006 Etna eruption



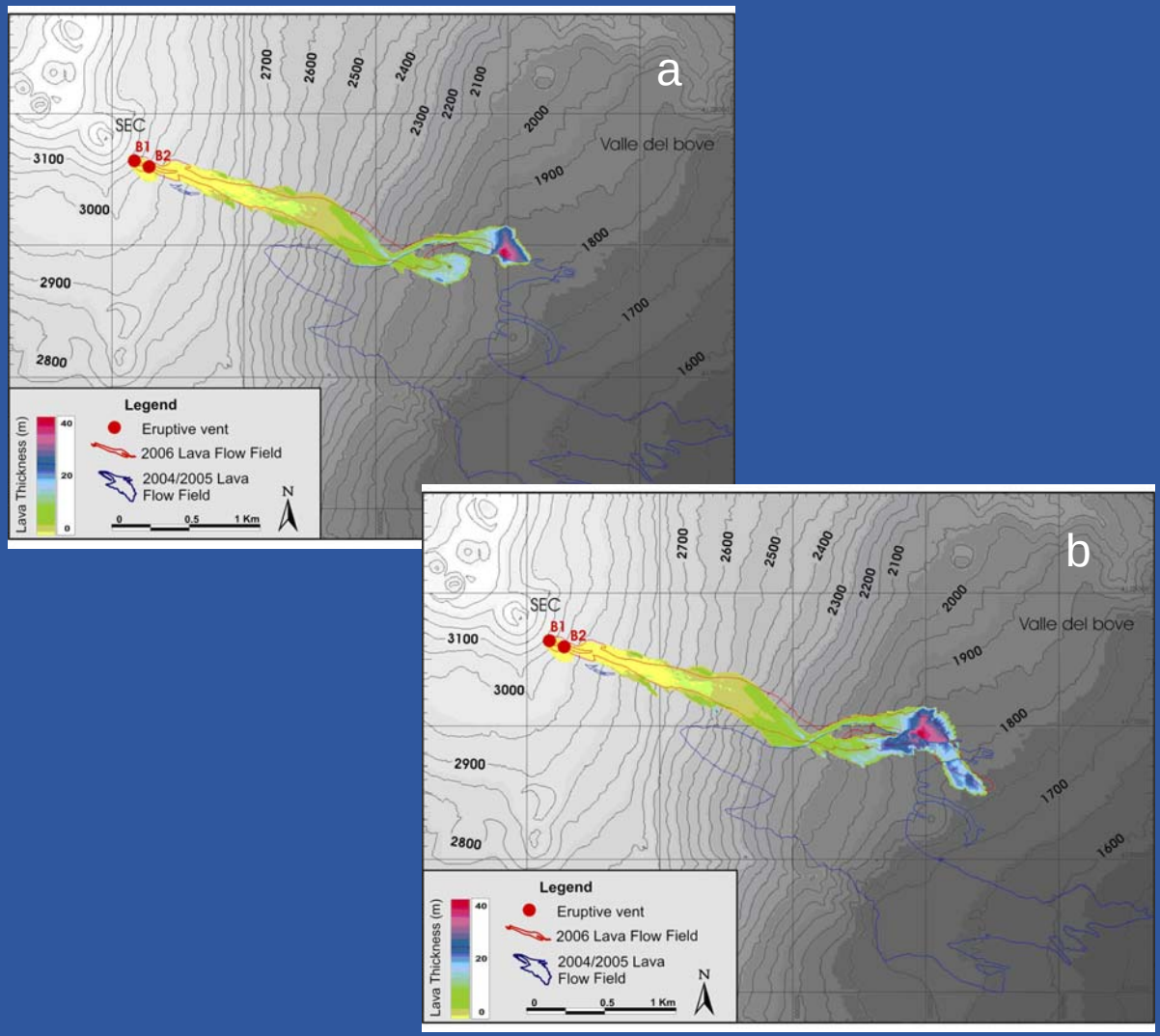
Simulated scenario of the 23 July 2006 computed without taking into account the presence of 2005-2005 Etna lava flows. The average value of effusion rate used for the simulation is 3 m^3/s for each vent. The red contour is the real map of lava flow updated to 17 July 2006.

2006 Etna eruption



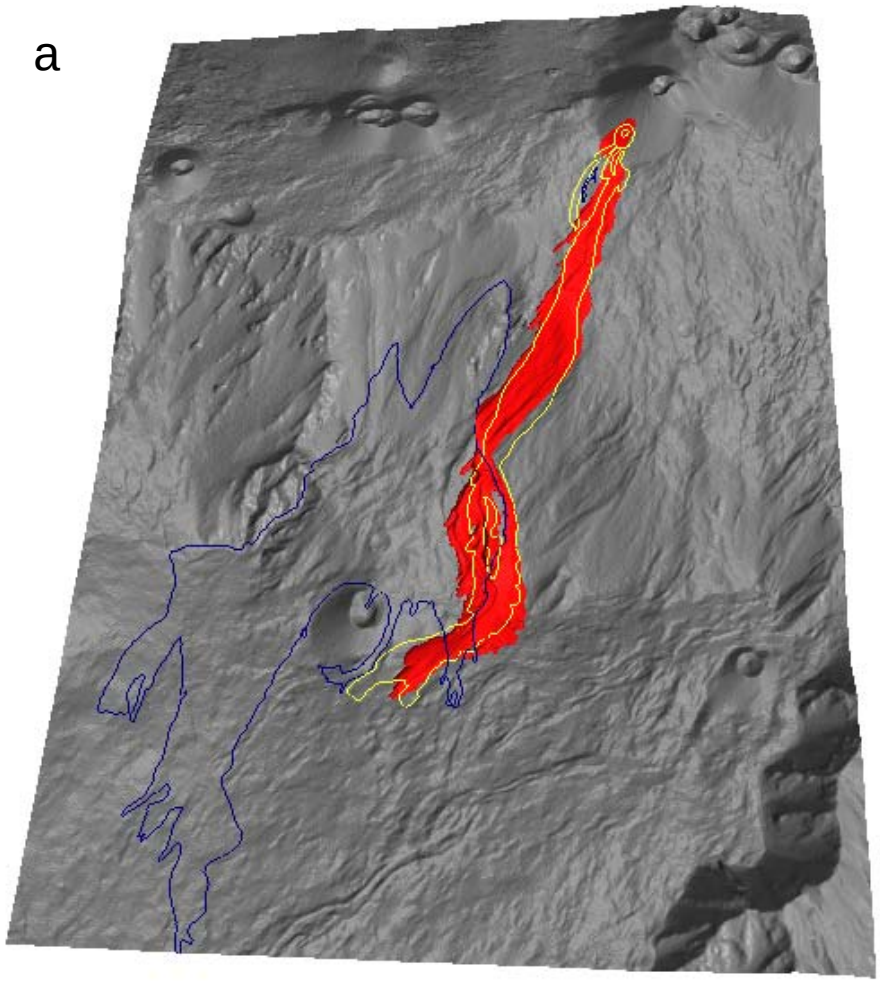
Simulated scenario of the a) 17 July 2006 and b) 23 July 2006. 2004-2005 Etna lava flow has been overlapped to the DEM, attributing a thickness of 100 m to the entire lava flow field. Effusion rate used for the simulation is represented by the green bell shaped in Figure 2.

2006 Etna eruption



Simulated scenario of the a) 19 July 2006 and b) 23 July 2006. 2004-2005 Etna lava flow has been overlapped to the DEM, attributing a thickness of 10 m to the entire lava flow field.

2006 Etna eruption



Simulated scenario in 3D of the a) 23 July 2006 and b) picture of real lava flow updated to 23 July 2006. The blue contour is the real map of 2004-2205 Etna lava flow, and the yellow one is the real map of 2006 Etna eruption updated to 23 July 2006

Differences between 2001, 2004 and 2006 cases

For the 2001 eruption we have :

- An accurate DEM before and after the eruption
- A measured effusion rate

For the 2004 eruption we have :

- An old DEM not updated after previous eruptions in the same zone
- A roughly estimated effusion rate
- Inaccurate ephemeral vent location

For the 2006 eruption we have :

- An old DEM not updated after previous eruptions in the same zone

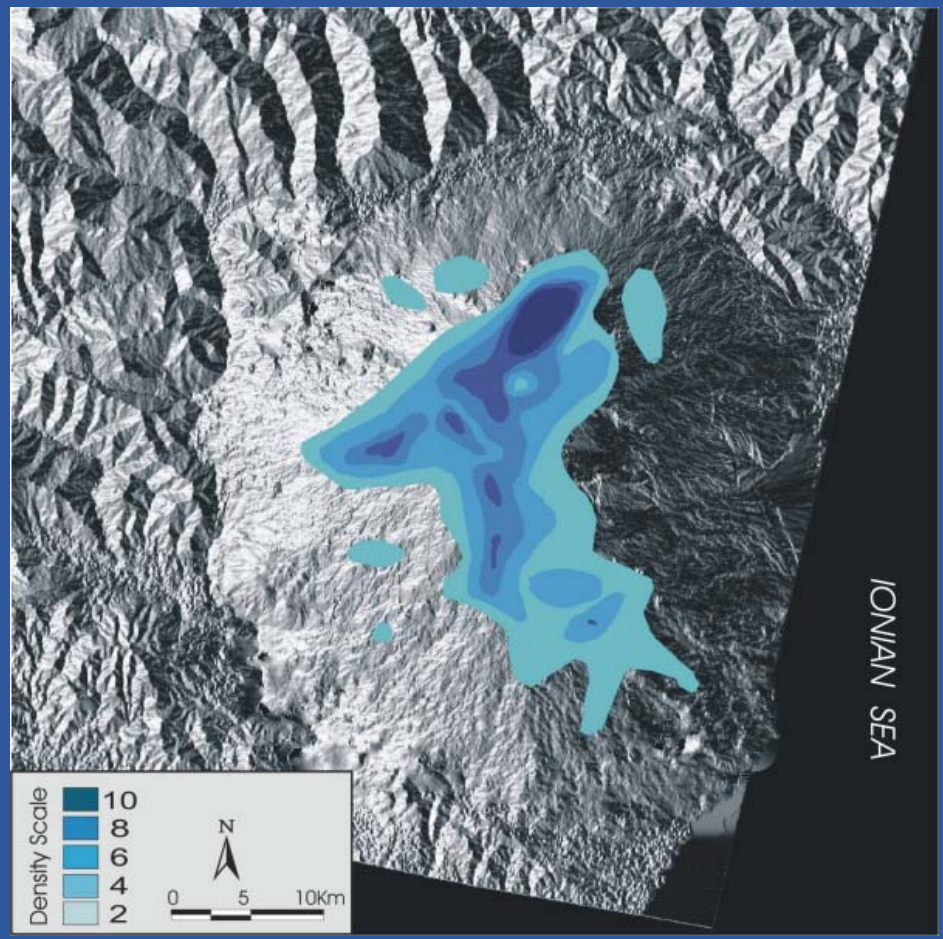
Obvious conclusion :
Not reliable input data ➔ not reliable simulation

Application : hazard maps

1) A preliminary zonation is necessary for identifying the regions with the highest probability of vent opening.
2) A set of reference values for the parameters of the simulation model based on the knowledge of past eruptions is estimated.
3) Magflow model is used to determine for each emission region the area that can be invaded by lava flows originated from sample points located in that region.
4) Last step is to assign the probability of lava invasions to interested region, calculated on the basis of the simulated lava flows.

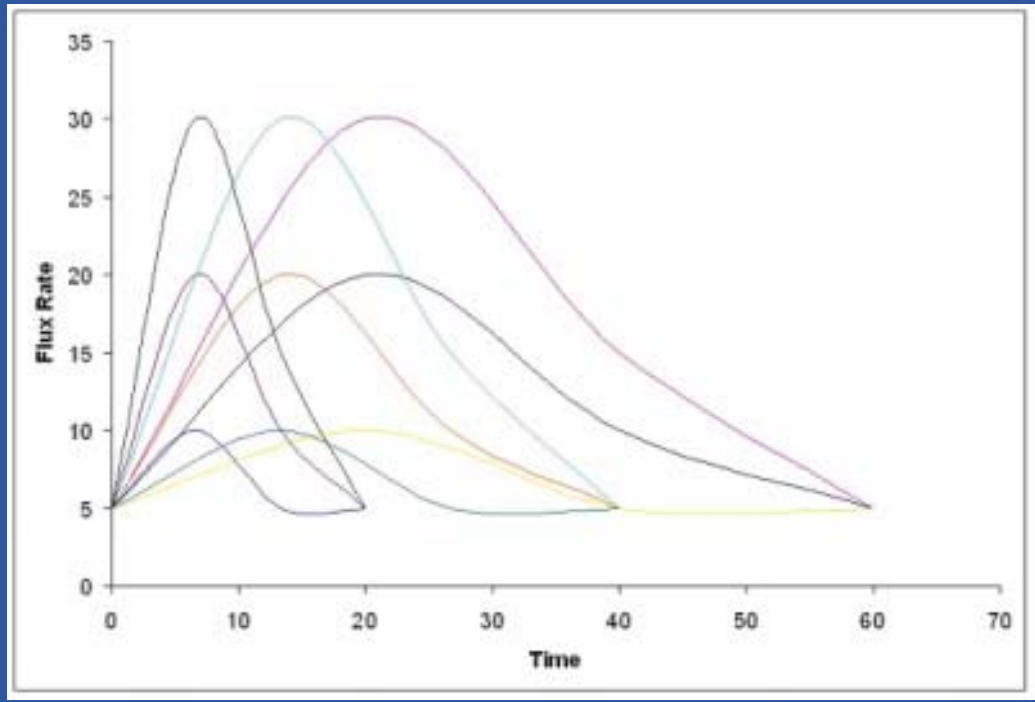
Step 1: establishing the vents

Equal-density areas of vents. Density scale represents the numbers of cones/4 km^2. Such surface is a better choice than one derived from the vent density map of Rasà et al., 1995.



Step 2: fixing the input parameters

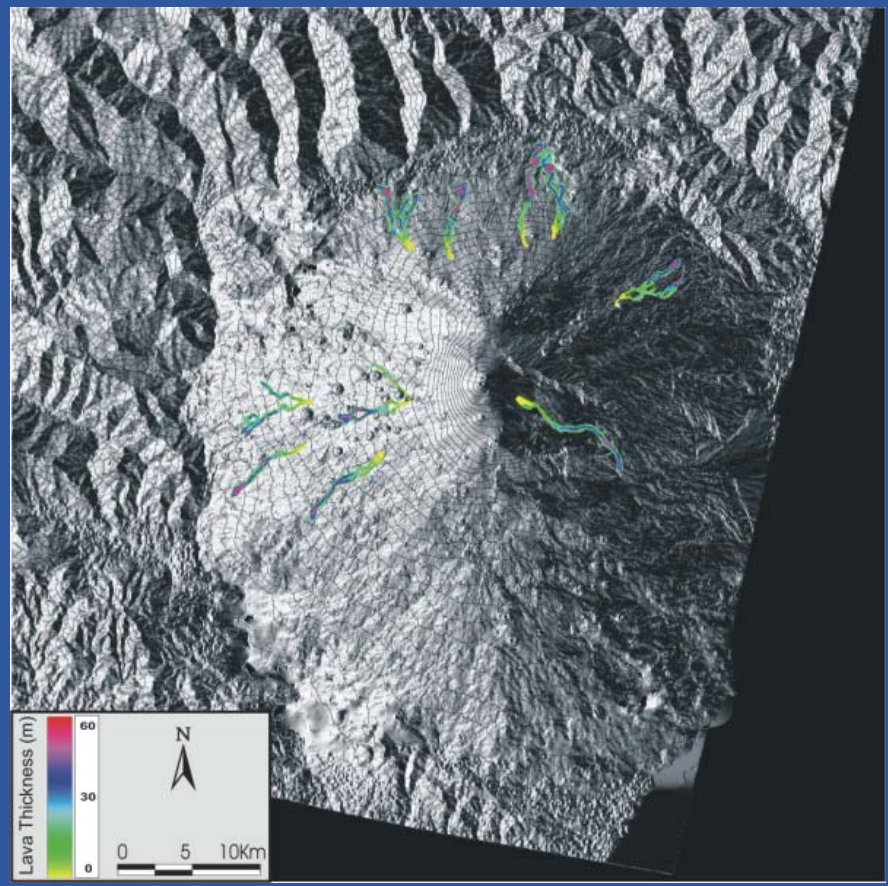
Three couple of values of flux rate (10, 20 and 30 m3/s) and days of eruption (20, 40 and 60 days) are associated to each vent. These couple are chosen in random way.



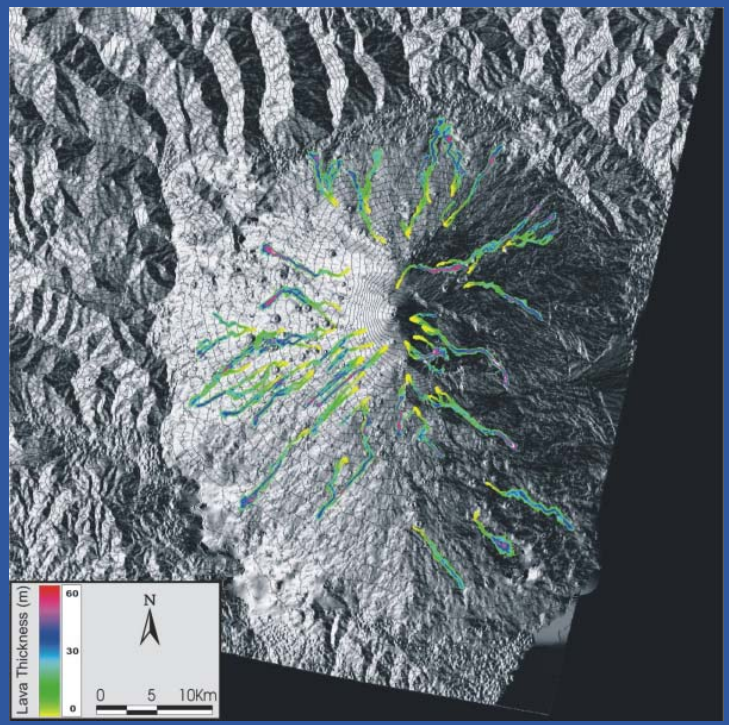
Step 3: running the simulations

Magflow is used to determine for each emission region the area that can be invaded by lava flows originated from sample points located in that region.

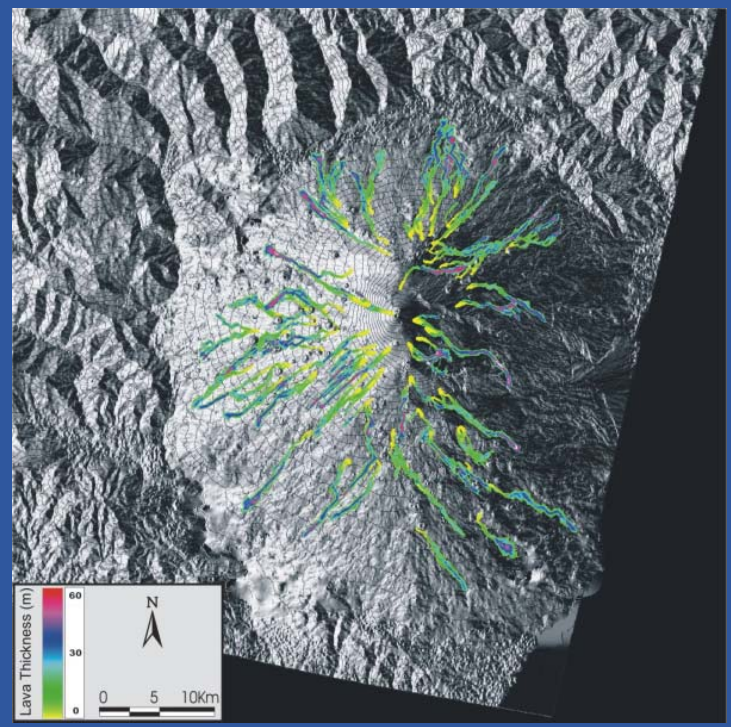
Maps of lava flows invasion after 10, simulations. Scale of colors represents different thickness.



Step 3: running the simulations



Maps of lava flows invasion after 50, and 100 simulations.

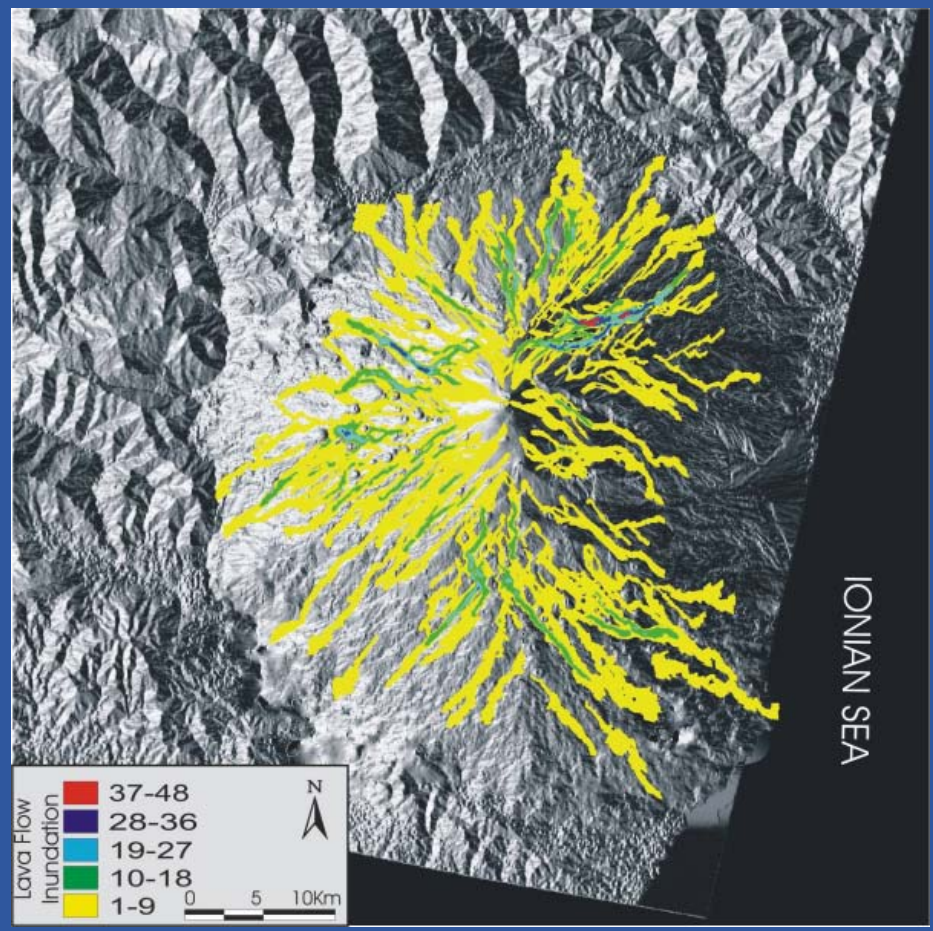


Scale of colors represents different thickness.

Step 4: generation of the hazard map

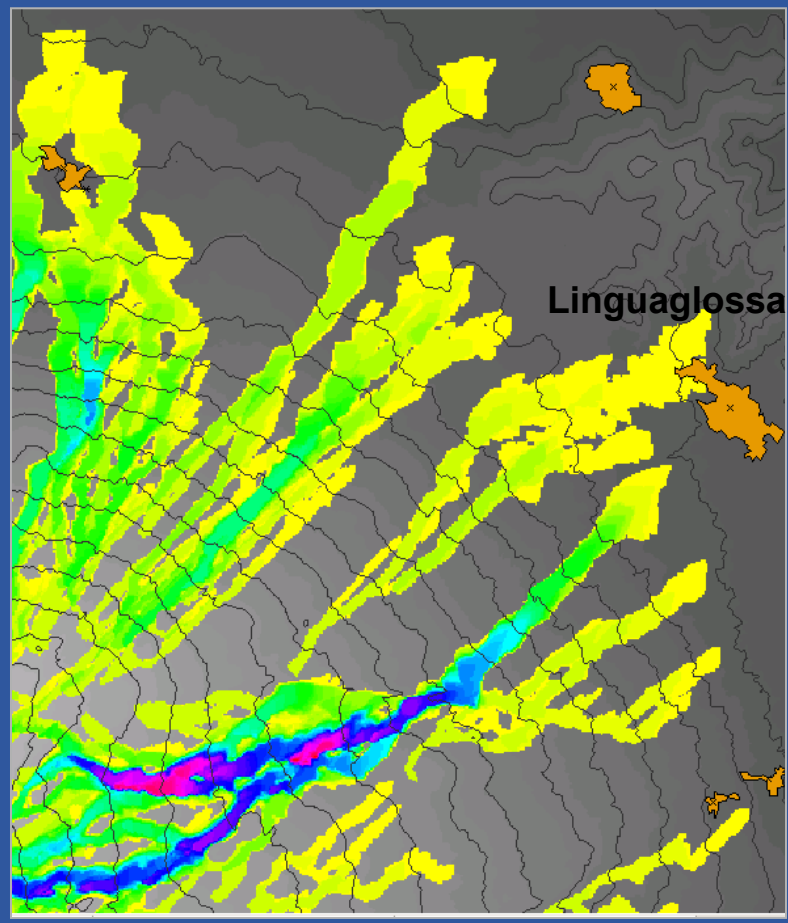
Hazard map for potential lava flows on Etna volcano. This mapping is the result after 810 simulations.

The five colored classes show the number of times that a given place has been covered by lava.

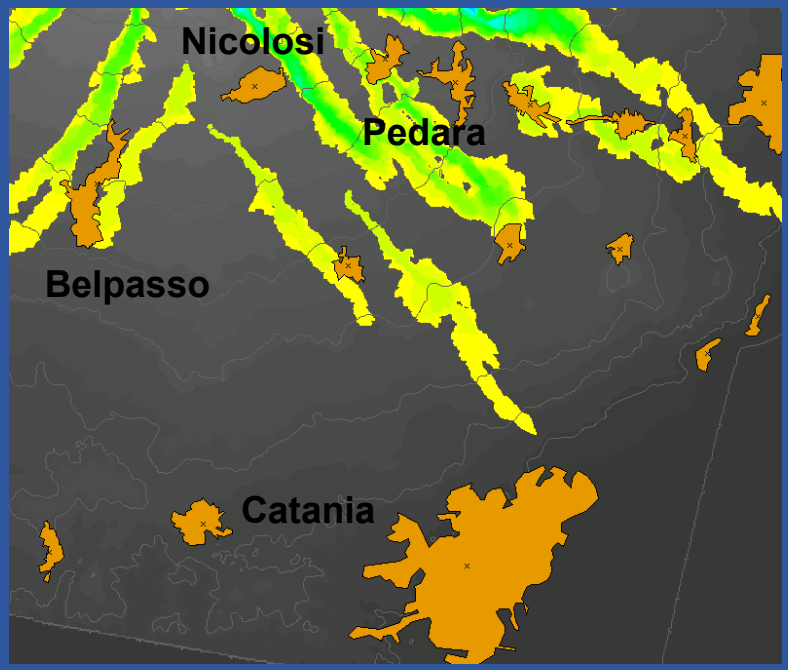


Details of hazard map

NE Zone



SE Zone



Other applications

We can apply the same methodology to :

- landslide
- floods
- forest fire

Conclusion

• The MAGFLOW model was able to reproduce quite accurately the time of advancing and of the lava flows, demonstrating its capability for real-time simulating the evolution of a lava flow.

• The accuracy of effusion rate measurement (by field or by remote sensing) must be improved.

• An historical cartographic database must be built.

• The DEM of Etna must be updated after each eruption.

Major problems arising from the lack of data sharing between different research groups and the lack of an efficient data management and updating strategy.