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MAPPING OF LAVA FLOWS FOR HAZARD ASSESSMENT

A. Ciraudo (1,2), C. Del Negro (1); A. Herault (3); A. Vicari (1)

(1) *Istituto Nazionale di Geofisica e Vulcanologia – Sezione di Catania, Italy, (2) Dipartimento di Matematica e Informatica – Università di Catania, Italy, (3) Laboratoire de Science de l'Information - Université de Marne La Vallée - Paris XIII, France*
(vicari@ct.ingv.it / Phone: +39-095-7165824)

Abstract

The development of physical-mathematical models able to describe the evolution of volcanic processes is fundamental in order to understand the dynamic of volcano and to estimate its dangerousness and risk mitigation. Hazard assessment was performed by simulating a number of lava flows from a set of initial data by using different parameter values of the volcanic system in a meaningful range of variation. A preliminary zonation was necessary for identifying possible emission regions with the highest probability of opening. Our model was used to determine the areas that can be invaded by lava flows.

Introduction

The activity of Mt. Etna is characterized by a great variety of eruptive processes that are potentially hazardous. Among them, lava invasion from effusive vents, also located close to urban areas, has produced from considerable to vast damage to the people living and working on the volcano flanks and over the coast of eastern Sicily, both in historical time and in the last decades (Fig. 1).

Fig. 1 – Lava invasion at Mascali village during the 1928 eruption of Etna.

Potential hazard assessment for these volcanic phenomena needs to be known in terms of both probabilistic maps for the medium-long periods, and forecast capability of ongoing eruptions. These studies are a key output of the modern volcanology, since they may help the local authorities and the Civil Protection in minimizing the damage of volcanic eruptions also through a correct use of the land or a safe use of infrastructures (Fig. 2).

The development of physical-mathematical models able to describe the evolution of volcanic processes is fundamental in order to understand the dynamic of volcano and to estimate its dangerousness and risk mitigation. The physical-mathematical models constitute a complementary methodology and are closely connected to the observation techniques of the volcanic system and those of laboratory and field. Finally, the researches of physical-mathematical models are crucial in the quantitative estimation of the dangerousness and therefore the volcanic risk, because their ability to define quantitative scenarios of a determined volcanic process.

We have, recently, developed a model for lava flow simulations based on Cellular Automatons (CA), called MAGFLOW (Del Negro et al., 2006, Vicari et al. 2006). The CA are discrete dynamic systems (cells), each of which may be in one of a finite number of states. In particular, in our model for each cell we have defined two state variables: thickness of lava and quantity of heat. The others parameters are deduced from these ones. The states of the cells are synchronously updated according to an evolution function that depend on cells own values and the values of neighbors within a certain proximity. The function that we have used is a steady state solution of Navier-Stokes equation for the motion of a Bingham fluid on a plane subject to pressure force in which we guarantee the conservation of mass both locally and globally.

Fig. **2** – Earthen barriers built at Etna volcano in 1983..

The proposed model represents the central part of an extensive methodology for the hazard assessment at Mt. Etna, currently under investigation. Hazard assessment can be performed by simulating a number of lava flows from a set of initial data (a record of past eruptions) and with different parameters of the volcanic system in a meaningful range of variation. In particular, a preliminary zonation is necessary for identifying possible emission regions with the highest probability of opening. After that, a set of reference values for the parameters of the simulation model based on the knowledge of past eruptions is estimated. So, 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. Last step is to assign the probability of lava invasions to interested region, calculated on the basis of the simulated lava flows.

Method and Results

The first step of the methodology required the zonation of the Etna volcano in different areas in accordance with a specific probability of vents opening. Five classes representing different probability zones were individuated (Del Negro and Rasà, 1997). After that, 276 vents were generated with uniform distribution, taking into account the probability density of each area (Fig. 3).

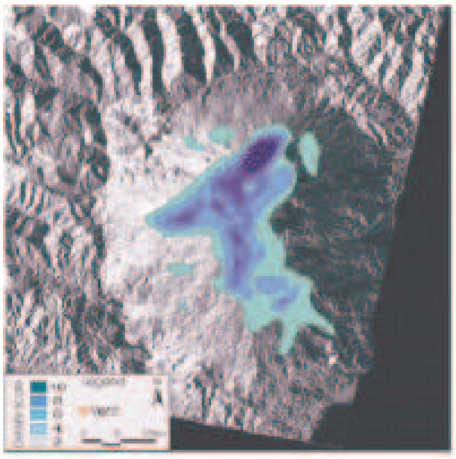

Fig. **3** – Equal-density area of cones. Density scale represents the number of cones/4 Km^2. The red points are the vents generated with uniform distribution.

On the knowledge of past eruptions, three different maximum values of flux rate were fixed, 10, 20 and 30 m^3/s. Then we established short, medium and large times of eruptions, setting respectively 20, 40 and 60 days of simulation. Combining these values with random distribution, obtained nine possible functions representing the variation of flux rate in relation to the time of eruption. The shape of the curves has been considered as a kind of bell, in which the eruption starts from a low value of flux rate, reaching its maximum value after a 1/3 of the entire time of simulation. After 2/3 of the maximum time of simulation halves the value of flux rate and, finally, gradually decrease until the end of the eruption is reached (Fig.4). This behavior was also observed during the 2001 Etna eruption (the only eruption for which data were available) (Coltelli et al., 2005).

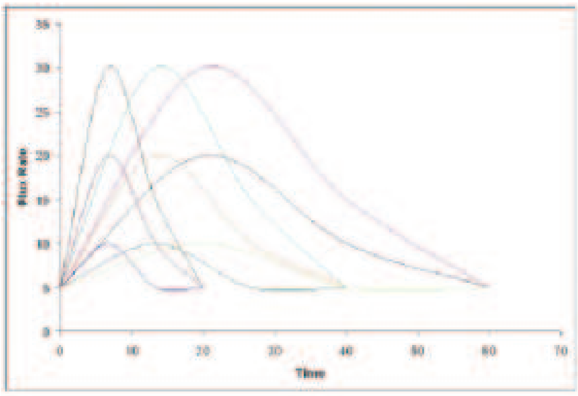

Fig. **4** – Values of flux rate-days of eruption used for the simulations.

So, three couples of flux rate – days of eruption values, chosen in random way, are associated with each vent. In this way a total of 828 simulations were obtained, three simulations for each vent, each one different from the other. At this point, the MAGFLOW simulator is used for identify all possible areas that can be invaded by lava flows. The simulations were performed using the typical parameters of Etnean lava flows reported on Tab. 1. Simulations were carried out using a relationship between magma viscosity and temperature by Giordano and Dingwell (2003). This viscosity model allowed to better follow the evolution in space and time of lava flow paths. Viscosity plays a very important part in the dynamics of lava flows. For this reason, the model for a viscosity force was chosen with care.

Parameter	*Value*	*Unit*
density (ρ)	2600	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

Tab. 1 - Typical parameters of Etnean lava flow used for the simulations

Figure 5 shows an evolution of this process. In particular, the areas invaded by lava flows after 10, 50 and 100 simulations with different vents are plotted. Last step of methodology consists to assign the probability of lava invasions to interested region, calculated on the basis of the simulated lava flows. Each point of the map will result covered by a different number of lava flows. Considering 5 output classes (but, of course, it is possible to change this number), and riparting in uniform way the number of time that a point was covered, it is possible to identify the zones with the highest probability of invasion (Fig 6). For example, the area at North of Etna volcano seems to be the principal areas at hazard.

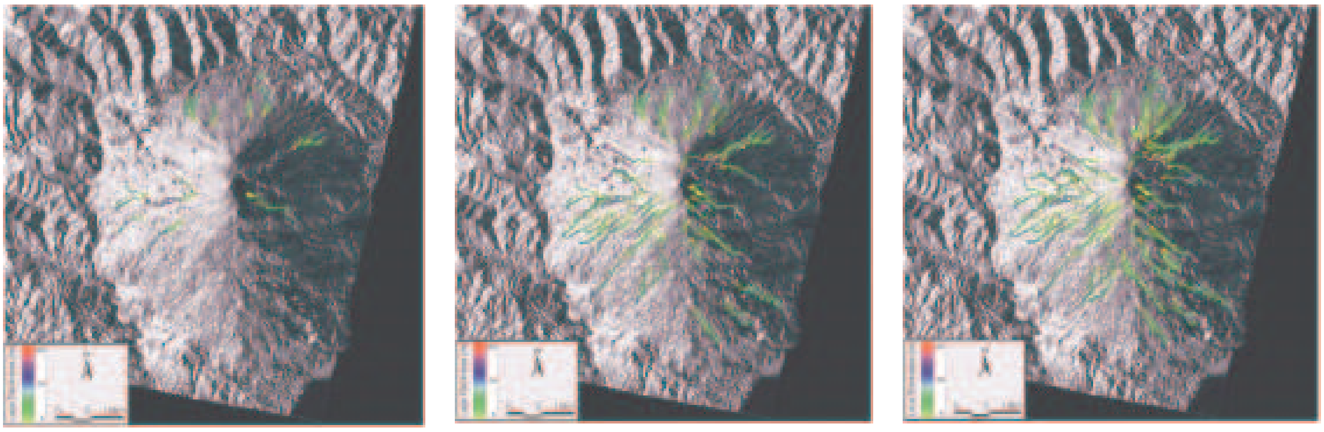

Fig. **5** – Maps of lava flows invasion after (a) 10, (b) 50 and (c) 100 simulations. Scale of colors represents different thickness.

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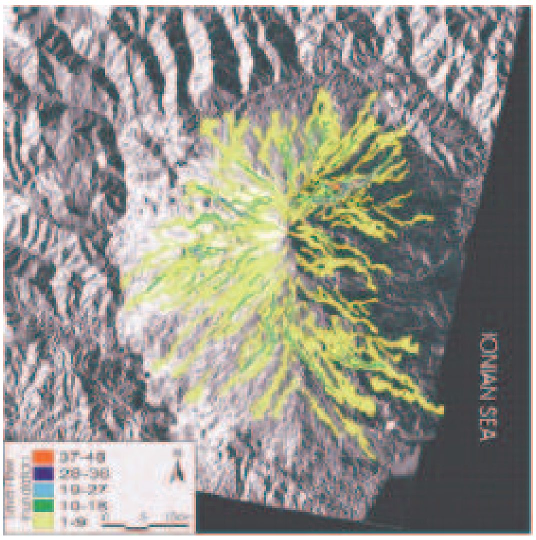

Fig. **6** –Result of probabilistic mapping of the potential lava flow inundation of Etna volcano. The scale represents the number of times that a place has been covered by lava.

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Conclusions

In this work a preliminary methodology of applying computer simulation techniques to the assessment of hazard from lava flows have been explored. Using this method, MAGFLOW can be used to provide a series of simulation of lava flows and to produce most probable eruption scenarios. Any number of simulations can be created by sampling the probability surface and parameter of simulator. Much improvement can be done, as for example separation of different type of eruption, or a better specification of probability surface of the location of future vents. Of course, this information influences heavily the result of final mapping.

References

Coltelli, M., Proietti, C., Branca, S., Marsella, M., Andronico, D., Lodato, L., 2005. Lava flow multitemporal mapping: the case of 2001 flank eruption of Etna, submitted to JGR

Del Negro, C., Fortuna, L., Herault, A., Vicari, A., 2006. Simulations of the 2004 lava flow at etna volcano by the magflow cellular automata model, Bull. Volcanol., submitted.

Del Negro, C., Rasà, R., 1997. Some efforts on the large-scale tectonic control of the volcanism in the Etna region from ground magnetic surveys on two etnean eccentric cones. IAVCEI General Assembly - Puerto Vallarta, Mexico 19-24 gennaio 1997.

Giordano, D., Dingwell, D. B., 2003. Viscosity of hydrous Etna basalt: implications for Plinian-style basaltic eruptions. Bull. Volcanol., 65 8-14 doi:10.1007/s00445-002-0233-2.

A. Vicari, A. Herault, C. Del Negro, M. Coltelli, M. Marsella, C. Proietti3, 2006. Modeling of the 2001 lava flow at etna volcano by a cellular automata approach, Environmental Modelling & Software, accepted.