Sub-Project V3_6 - Etna

Responsibles:

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Mt. Etna is one of the most active and investigated volcanoes in the world. In particular, the last two decades have represented a time period characterized by a great variety of eruptions and by a large data acquisition, both instrumental and from field surveys. As testified by the conspicuous literature, the present knowledge of the different eruptive styles of the volcano is rather good and includes the study of Plinian eruptions in historical age, small phreatic eruptions at the summit craters, long quiet lava effusions, as well as large flank eruptions. Also the internal structure of the volcano is roughly well-known, even though some crucial questions, as the existence or not of a main magma chamber, remain still unanswered and more detailed information are required for the shallower part of the volcano. Geological maps of the volcano (funded by the National Geological Survey and other projects) are in progress and many petrologic features of the erupted magmas are known. The eruptive mechanisms of several single eruptions have been well-studied even if an integrated multidisciplinary approach was often lacking. Significant statistical investigations on the eruptive precursors were lacking too. The modelling and numerical simulation of pre-eruptive processes have been mostly carried out by using inverse models and need to be complemented by promising results coming from direct analytical and numerical models. During the last decades, new modern techniques of volcano monitoring have been also implemented in order to mitigate the volcanic hazard. The amount of available data produced represents a huge database rich of information. However, a significant amount of work is still required to understand the volcano behavior and hazard issues. Different kinds of hazard affect the volcano and the surrounding areas: short-lived explosions (threatening tourists and/or scientists close to the summit craters), ash clouds (threatening civil aviation), lapilli/ash fallout and lava flows (affecting large inhabitated areas), earthquakes triggered by magma intrusions, landslide (also submarine), toxic gas emissions (Rn and/or CO2). However, despite the frequent occurrence of volcanic activity, significant steps forwards still need to be done in the quantification of its hazards. Lava flows and the generation of small- to medium-scale ash columns represent certainly the most common hazards. About lava flows, the production of accurate lava flow invasion maps represents the main goal for the assessment of the medium and long-term hazard associated to this phenomena. Similarly, the development of reliable quasi real-time lava flow models will allow to forecast different scenarios of lava propagation and to plan the appropriate mitigation measures. As far as the explosive activity is concerned, the recent 2001 and 2002 eruptions of Etna have clearly shown the huge potential impact of this phenomenon on the city of Catania as well as on the Fontanarossa and Sigonella airports that were forced to interrupt traffic operations with a huge economic loss. On this respect, it is necessary to improve the present observational and forecasting capabilities regarding the dispersal of the ash cloud, also in the light of the specific tasks that have been assigned to INGV by the Ente

Nazionale per l'Aviazione Civile. It is therefore necessary to produce hazard maps, able to provide robust information on the medium- and long- term hazard, as well as nearly real-time forecasting tools able to simulate the ash clouds dispersal and characteristics. Eruptive events as well as hazard maps should be possibly described in terms of probability of occurrence of specific phenomena at a given place and time by producing probabilistic event/logic trees and also considering the uncertainty associated to the system. Similarly, the identification and characterization of precursory signals represent a fundamental issue that would drastically improve our capability to forecast the volcanic phenomena.

In the following pages the project will be briefly presented describing its main tasks and workpackages together with an indicative list of possible deliverables.

Task 1. Plumbing system and structure of the volcano from the lithosphere to the surface

The knowledge of the plumbing system and structure of the volcano plays an important role in order to improve our understanding of its behaviour. The existence, location and properties of deep and shallow magma bodies are indeed fundamental for a correct interpretation of monitoring data and to better forecast the style of future activity. Magmatic properties, such as composition and volatile contents, are also necessary to better constrain the eruption dynamics. Similarly, the characterization of the volcano structure, in terms of major active faults and fractures but also of physical and mechanical properties, is crucial for a better interpretation of monitoring data and production of susceptibility maps.

WP 1.1 Definition of the plumbing and magmatic system

Deliverables:

1. Location and characteristics of the main magma body
2. Definition of feeding structures and shallow magma batches
3. Determination of composition and volatile content of magma

WP 1.2 Definition of the volcano structure

Deliverables:

1. Definition of the edifice and basement structure
2. Distribution of active faults, eruptive fractures and vents
3. Definition of the conduit/dike system within the volcanic pile
4. Influence of regional and local tectonic structures in the magma uprising and stocking
5. Susceptibility maps based on geological, geochemical, magnetic, gravimetric, electrical , seismological, and ground deformation data

Task 2. Hydrologic and hydrothermal settings

The existence of underground water, at various depths, interacting with magma and magmatic fluids can drastically affect the style of the eruption and the interpretation of monitoring network data. To the aim to better understand the nature and eruptive mechanisms of Etna’s activity it is therefore necessary to improve our knowledge of the hydrologic and geothermal systems within the volcano and particularly in its upper part. Correlation of underground fluid circulation with precipitation data and quantification of heat and mass flows from the volcano appear also to be relevant to better constrain the nature of explosive activity (magmatic vs phreato-magmatic activity).

WP 2.1: Definition of the hydrologic and hydrothermal systems and acquifers

Deliverables:

1. Physical models of liquid/vapor circulation in the geothermal systems
2. Definition of the water table at middle-high elevations
3. Systematic measurements (space and time) of thermal and gas fluxes
4. Analysis of rainfall and snowfall data and correlation with explosive activity

5. Quantification of the magmatic and non-magmatic components of fluids emitted at the surface

Task 3. Physical and chemical properties of magma and volcanic rocks

The knowledge of the physical and chemical properties of magma and volcanic rocks are necessary to provide realistic constitutive equations to the interpretation of monitoring data and theoretical descriptions of the eruptive phenomena. Rheological properties of the multiphase magmatic mixture, volatile solubility data, but also density, velocity, permeability, porosity, conductivity and magnetization of the volcanic structure are just some examples of fundamental properties used by direct and inverse models that need further investigations.

WP 3.1. Physical and chemical properties of the magmatic mixture

Deliverables:

1. Viscosity of the magmatic mixture (vs composition, crystals, bubbles, volatiles, temperature)
2. Yield strength of the magmatic mixture (vs composition, crystals, bubbles, volatiles, temperature)
3. Volatile solubility data and correlations
4. Gas diffusivity

WP 3.2. Physical and mechanical properties of volcanic rocks

Deliverables:

1. Visco-elasto-plastic properties of the edifice and their variation with T and P
2. Density and velocity models of the volcanic edifice
3. Permeability, porosity, capillary pressure and texture of the rock fabric
4. Electrical and thermal conductivity models of volcanic rocks
5. Zeta potential and wettability of the rock surface

Task 4: Modelling and Simulation of Pre-eruptive Processes

This task is devoted to the development, validation and application of theoretical models of pre-eruptive processes typical of Etna’s activity. The models developed should employ the observational and experimental data determined in Tasks 1-3 and should represent an effective tool to better interpret the monitoring data during pre-eruptive phases. Models able to correlate the edifice deformations observed to a specific source, taking into account the perturbations due to the topography and medium anisotropy, are particularly needed. Similarly, models describing the dynamics of the intrusion of the multiphase magmatic mixture into the conduit/dike system should provide further constraints in the interpretation of monitoring data and eruptive mechanisms occurring during the magma ascent. Analogue experiments able to scale some features of the pre-eruptive dynamics could also be considered.

WP 4.1. Deformation modelling

Deliverables:

1. 1D/2D Analytical models of medium deformation

2. 2D/3D transient models of stress/strain fields due to the action of conduits, dikes, sills, etc.
3. Temporal simulation of expected deformation and potential fields
4. Experimental analogue models of structure deformation and collapse

WP 4.2. Magma intrusion modelling

Deliverables:

1. Multidimensional, multiphase and transient models of magma intrusion in conduit/dikes
2. Fluid-structure models of magma intrusion with phase-change and heat transfer to conduit walls

Task 5. Identification and characterization of precursors

This tasks is focused on the identification and characterization of precursory signals and therefore is strongly based on the quantitative analysis of monitoring activity. Complete and long time-series of geophysical, geochemical and petrologic data are indeed available at Mt. Etna. Quantitative definition of precursors - in terms of threshold values, time-window of validity, kind of "predicted" eruptions needs - as well as validation of precursors - in terms of number of number of successes, false alarms, and failed predictions - are the main goals. Multidisciplinary approaches and blind tests are also required.

WP 5.1. Background levels of signals at Etna

Deliverables:

1. Definition of the ranges of variation of geophysical, geochemical, petrologic, etc. data representing the background levels at Etna
2. Definition of "critical levels" for each monitoring signal

WP 5.2. Identification of precursory signals

Deliverables:

1. Creation of a multi-parametric database of monitoring signals
2. Quantitative statistical models for the identification and quantification of precursory signals
3. Analysis of Coulomb stress failure (magma intrusions triggering earthquakes and large earthquakes favouring magma intrusions)
4. Automatic or semi-automatic warning systems for forecasting eruptive events

Task 6. Reconstruction of the eruptive record and characterization of eruptive typologies

This task is devoted to the production of an as much as possible complete record of the Etna eruptive history through the completion and integration of existing studies and datasets on the history of the volcano. In particular, it is necessary to integrate the knowledge coming from the detailed reconstructions of deposits with the information deriving from catalogues and historical chronicles. Each eruptive events reported in the so obtained catalogue should also be classified in terms of the main properties characterizing the phenomenon such as its typology, age, magnitude, intensity, composition, product dispersal, and so on. The final dataset will indeed represent the basic information for the carrying out of numerical simulations of the eruptive phenomena and for the quantification of the related probability of occurrence. A specific effort is finally required for the production of a reliable and accurate digital elevation model of the volcano to be used in the lava flow simulations.

WP 6.1. Reconstruction of the eruptive history on the basis of geological and paleomagnetic studies and of historical chronicles

Deliverables:

1. Database of the eruptive history as reconstructed on the basis stratigraphic and paleomagnetic studies
2. Database of the eruptive history on the basis of historical chronicles and catalogues
3. Integrated database summarizing the whole eruptive history

WP 6.2. Characterization of expected eruptive categories

Deliverables:

1. Definition of eruption categories to be considered in the hazard scenarios
2. Characterization of eruption categories in terms of magnitude, intensity, composition, product properties, etc.

WP 6.3. Production and update of a digital elevation model of the volcano

Deliverables:

1. Updated digital elevation model of the volcano
2. Database of the available digital elevation models of the volcano in the last decades

Task 7. Probability of the expected events

On the basis of the eruptive record reconstructed in Task 6 and the analysis on monitoring data it is possible to identify the scenarios and eruptive typologies that should be investigated for hazard purposes. A formal way to do this is to implement and use statistical tools and techniques, such as the Bayesian approach through the definition of Event and Logic Trees, able to quantify the probability of occurrence of a specific event. By using these techniques is also possible to take into account the uncertainty related to the dynamics of the eruptive process itself as well as the uncertainty related to the lack of knowledge.

WP 7.1. Statistical analysis of the eruptive records

Deliverables:

1. Characterization of the volcano behaviour in terms of recurrence time, steady-state vs cyclic behaviour, etc.

WP 7.2. Construction of Event/Logic Trees and estimation of probability of specific hazards

Deliverables:

1. Definition of the structure of the trees
2. Conditional probabilities of specific levels of the trees
3. Link of tree's probability to monitoring data and models
4. Devising of appropriate warning levels

Task 8: Simulation of Eruptive Processes

The quantitative description of the dynamics of the eruptive phenomena requires the development, validation and application of accurate and robust physico-mathematical models able to forecast the spatial and temporal evolution of the volcanic processes. In particular, given the most common styles of activity exhibited by Mt. Etna, the development of conduit flow, lava flow and ash dispersal models has the highest priority. Models based on different physical formulations and approaches (deterministic versus probabilistic, Eulerian vs Lagrangian, etc.) are welcome in order to make possible model inter-comparisons and more robust forecasts of the phenomena. Models should also use, as much as possible, data deriving from the other tasks such as observational data, for model validation, and experimental data, for constitutive equations. The study of post-eruptive processes could also be included if considered relevant.

WP 8.1. Modelling and simulation of magma ascent.

Deliverables:

1. 1D/2D models of magma ascent
2. Numerical simulations describing the dynamics of magma ascent
3. Numerical simulations describing the interaction between magma and external water
4. Flow conditions at the vent to be used in the modelling of the atmospheric processes for different eruptive scenarios

WP 8.2. Modelling and simulation of lava flows.

Deliverables:

1. 2D/3D deterministic models of lava flows
2. Numerical simulation results describing the evolution of single lava flows and their dynamics
3. Probabilistic models of lava flow and estimates of invasion areas
4. Inter-comparison between models

WP 8.3: Modelling and simulation of ash dispersal.

Deliverables:

1. 1D/2D/ 3D models of the eruptive plume
2. 2D/3D models of ash cloud dispersal
3. Numerical simulation results of the dynamics of the rising plume
4. Numerical simulation results of the dynamics of the ash cloud dispersal
5. Inter-comparison between models

Task 9: Hazard Assessment

This task is specifically aimed at the carrying out of products able to provide quantitative estimates of the hazard at Mt. Etna. These include hazard maps able to identify the most dangerous areas surrounding the volcano as well as numerical forecasting simulations to be used during the crisis for the quantitative description of the hazard of the phenomena. Hazard maps should describe the spatial distribution of specific hazardous characteristics of the eruptive event as well as specific actions associated to the phenomena. Forecasting simulations should be used in quasi real-time in order to predict the evolution of the phenomena and their hazard on the surroundings. Characterization of the specific hazardous actions produced by the ash fallout on the environment is also required Quantification of hazard in terms of probability according to the lines described in the Task 7 is particularly welcome.

WP 9.1. Medium- and long-term hazard mapping.

Deliverables:

1. Hazard maps of lava invasion
2. Hazard maps of ash fallout

WP 9.2. Hazard forecast simulations

Deliverables:

1. Simulation forecasts of lava flow invasion areas
2. Simulation forecasts of lava flow evolution
3. Simulation forecasts of ash dispersal in the atmosphere
4. Simulation forecasts of ash dispersal on the ground
5. Simulation forecasts of the hazardous actions produced by the ash