PROJECT V4

Conception, verification, and application of innovative techniques to study active volcanoes

Responsibles:

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Objectives:

The development of innovative and quantitative methods is one of the main ingredients for future progresses in volcanic risk assessment and management at long- and short- term time scales.
The complexity of volcanic systems originates from the strong heterogeneity of their internal structure (in terms of spatial variation of physical rock properties) and the large variety of thermo-mechanical processes which may precede and accompany the magma rise and eruption. The most comprehensive understanding of volcanic processes necessarily calls for a multi-disciplinary, integrated approach of data acquisition, analysis and modeling.
During the past three decades, we have been witnessing a strong technological development leading to a rapid growth of multidisciplinary studies of volcanoes. The controlled, repeatable experimentation is nowadays replaced by dense monitoring projects, where the analysis strategy is often dictated afterwards, depending on the data produced. Volcano monitoring networks (geophysical, geochemical, geodetical,..) produce terabytes of data, only a small fraction of them is practically used for research and/or survey purposes.
It comes out the need for implementing new strategies of data management able to analyze and mine in the near-real-time huge data flows, having the targets 1/ to exploit the whole available information, 2/ identify and measure quantitative risk indicators useful for volcanic risk monitoring and emergency management and 3/ develop advanced tools for process simulation and event prediction based on the real time analysis and modeling of observed data.
Due to the multi-disciplinary nature of the object under study, innovative approaches and techniques for volcano monitoring may concern an ultra-wide disciplinary domain (geophysics, geochemistry, geology, remote sensing,…). The present project focuses on a restricted number of tasks which are believed to be prior in terms of needed scientific effort and development and possible gain of knowledge about volcanic processes:

- Volcanic hazard estimation based on a quantitative probabilistic approach
- High resolution imaging of the volcanic structure by using advanced seismic tools
- Real-time seismic and thermal monitoring of volcanoes integrating on-land and sea-bottom systems of observation

State of the Art:

Quantitative methods for probabilistic estimation of volcanic hazard
The probability of any particular area being affected by a destructive volcanic event within a given period of time defines the volcanic hazard whose quantitative estimation is actually a challenging

task due to the scarce number of databases collecting sets of seismic variables relative to unrest and eruptive phases of explosive volcanoes. The probabilistic nature of such an important issue derives from the fact that, as the largest part of natural phenomena, volcanic activity is a complex process, characterized by several and usually unknown degrees of freedom that are often linked by nonlinear relationships. The result of this complexity is an intrinsic (and maybe unavoidable, at least over time intervals of more than few days) unpredictability of the time evolution of the volcanic system (except in sporadic cases) from a deterministic point of view. Despite the huge practical importance of this issue, a full probabilistic hazard estimation and quantitative levels of alert have not been yet proposed for almost all the worldwide active volcanoes.

The present project proposes to adopt and implement innovative approaches based on a quantitative estimation of any kind of volcanic hazard and individual risk, by merging theoretical models of the eruptive process, past (historical and geological) data, and data from monitoring of the volcano. At this purpose, we intend to implement quantitative probabilistic schemes such as Bayesian Belief Network (BBN), and “Event Tree”. The methods allow representing all the possible relevant events connected to the volcanic activity and calculating the Bayesian probability and uncertainty. The method also allows aleatoric and epistemic uncertainties of the model to be dealt with in a formal way, and all to be accommodated in a hazard or risk assessment.
Notably, this way of thinking and strategy concerns the delicate problem of defining and assigning an appropriate volcanic alert levels, based on rigorous, quantitative analyses of observations, theories, models and expert opinions. The challenge is to formulate an approach that can satisfactorily provide a synthesis of all direct and indirect pieces of information into a framework for supporting alert level decisions.

<u>High resolution imaging of the volcanic structure</u>
Tomographic models inferred from the inversion of first arrival times have not a sufficient resolution to accurately define the morphology and location at depth of the main crustal reflectors (included the top of the magma reservoir) beneath volcanoes. The imaging of complex, in-land, volcanic structures (irregular topography, highly heterogeneous propagation medium) by seismic reflection is a challenging task both from the data acquisition and modeling point of views: unmodeled multi-path arrivals, very energetic direct and ground roll phases, diffraction and scattering phenomena may often lead to poor quality of reflected signals. It is therefore necessary to develop new techniques of data processing and analysis able to work on unconventional data acquisition geometries (sparse, irregular, distribution of source/receivers) and complex waveforms in the complete incidence angle range (from near-vertical to wide-angle). This requires a further step in the analysis of seismic reflection images which implies the modeling of reflection wave amplitudes vs offset (incidence angle) which can give important insights about the physical/lithological nature of the reflectors. The spatial variations of both P and S velocities fields, as represented by tomographic images, can be analyzed and interpreted as lithological and rheological features for characterization of rocks. This interpretation is made by using theoretical modeling of velocities through biphasic structures based on field data as well as from laboratory experiments.

The volcano seismology today aims at the understanding of the dynamics of seismic sources associated with the injection and transport of magma and related hydrothermal fluids. The modeling of the seismic wave field in 3D heterogeneous structures is a key factor in the studies concerning the translation of the seismic observations into quantitative information about the dynamics of the magmatic system. The advances of computational environments allow for the successful applications of numerical algorithms for the simulation of the seismic wave field in 3D heterogeneous velocity structures. The conventional 3D approaches so far applied in non-volcanic areas describe only approximately the dissipative medium and do not account for the possible anisotropy. Innovative methods for simulating the three-dimensional seismic wave field radiating in a heterogeneous, anisotropic and anelastic volcanic structure will be developed in the present project. It is expected that the hazard evaluation and monitoring of the volcanic activity would be greatly improved by the simulation of the observed seismic signals by means of advanced algorithms that take into account the 3D complex structure.

The volcano structural complexity are well quantified by the parameters of seismic attenuation and anisotropy. New techniques for imaging the attenuation properties, based on non-global linear strategy, reveal their importance especially when a joint interpretation of the (scattering and intrinsic) attenuation and velocity is possible. With this approach high intrinsic attenuation zones may be distinguished from highly heterogeneous zones (strong scattering strength) helping in the detection of possible magma chambers. The detailed study of the crustal anisotropy , moreover, adds important information to the image of the heterogeneities, through the systematic spatial analysis of the splitting parameters. Application of these techniques in volcanic environments may provide useful hints for the location and characterization of buried heterogeneities associated with structural complexities. Based on the availability of advanced seismic waveform modeling techniques, the present project propose the validation and tests on synthetic data of developed tools for measurements of anisotropic and anelastic parameters simulating realistic complexity of the propagation medium and lay-out acquisition.

<u>Real time seismic and thermal monitoring, integration of sea-bottom and on-land seismic networks</u>
The existence of national infrastructures (managed by INGV) for the operation of seismic monitoring tasks in Italian volcanic areas allows the development of new and innovative observational tools. The availability of a truly real-time, seismic system able to process and analyze huge streams of multi-channel data and communicate with remote probes installed on- and offshore (i.e., a sea-bottom observatory continuously linked to the on land network) is of particular relevance for the process of decisions and actions to be taken during emergency phases. Available continuous seismic recordings can be used to develop quantitative almost-real time signal analysis aimed at the measurement of indicators of risk monitoring and emergency management, detection of exceeding alert thresholds and activation of automatic *early-warning* procedures and protocols of decisions-making. The seismological monitoring needs different analysis techniques for covering the wide manifold of seismo-volcanic signals. Locations suffers for the complex structure of volcanoes, so 3D velocity models (from seismic tomography) greatly improves their quality. High resolution tomographic velocity models for several Italian volcanoes are now available, and accurate techniques for earthquake location and mechanism determination have to consider the heterogeneous nature of the propagation medium. The best suited location tools for complex structures are non-linear search based methods such as NonLinLoc developed by A. Lomax. Furthermore, the use of Equal Differential Time technique improves the robustness of locations by neglecting large outliers. The most dangerous italian volcanoes (Vesuvius and Campi Flegrei) show currently a predominant volcano-tectonic seismicity, but tools for the analysis of LP and VLP signals should be rapidly working in case of unrest and be able to provide a rapid estimation of the source location and mechanism (moment tensor) parameters. In addition, an efficient seismological monitoring system of volcanoes needs both a rapid real-time automatic analysis of data and long term databases for a comparison of the current volcano status with the past activity. This result may be obtained developing procedures that carry out continuous analysis, putting results in a database, accessible via a user-friendly web interface.

Considering that most of Italian active volcanoes have their edifice entirely or partly submerged, seismological instruments deployed on sea bottom with real time data transmission to onshore centers will be an important new tool for volcanic monitoring in the next future. Data acquisition of earthquake waveforms on the sea bottom is performed since several decades using Ocean Bottom

Seismometers (OBS). Usually data are acquired in continuous mode and locally stored over periods from some weeks to more than one year, according to the autonomy of the batteries. A retrieval system controlled by acoustic command, releases the ballast allowing the OBS pop-up. Data are available only after the recover of the instrument. Monitoring of volcanic activity requires data transmission in real or near-real time and new technology to retrieve the data are now in development. Recently data acoustic transmission systems for a sea bottom instruments are under development to extent real time data acquisition to the seafloor in the framework of a cooperative project seeing the partnership of research (INGV, University of Naples) and industrial partners (Alenia WASS). Integrating the experiences and know-how gained by carrying out this and other linked projects for sea bottom observatories conducted at Roma-2 section of INGV, the present project will design, develop and realize in a prototype form, sea bottom seismic station with real time transmission connected to the monitoring system of Neapolitan volcanic area.

Ground-based thermal imaging (direct ground measurements and infra-red imaging) has recently been introduced in volcanology and applied to a number of different volcanic phenomena. Excellent results have been obtained during 2002-03 Etna and Stromboli eruptions, when daily thermal imaging measurements allowed us to observe magma movements within the summit conduits, the opening of fissure systems, the development of fractures on the flanks, and also to discriminate lava flow field structures such as lava tubes, ephemeral vents, tumuli and to distinguish active lava flows. Thermal images can be also used to provide quantitative measures of lava effusion rates. In this project, we intend to develop new measurement techniques, and quantitative computational methods to allow near real-time analysis of thermal imagery based on the already existent observational experiences carried out on several Italian volcanoes. For instance the TIIMNet project (Thermal Infrared Imagery Monitoring Network) allowed to design and to develop a volcanic surveillance system for the continuous monitoring of the shallow thermal structure of active volcanoes. The technological approach was specifically developed for Vesuvius and Solfatara craters, based on the integration of image monitoring systems, in the thermal IR wavelengths range, with the existing geochemical surveillance systems.

Description of the Activities:

The project is organized in 3 Tasks, that will be achieved through the development of research activities coordinated in specific 11 Work-Packages.
The Tasks have been identified to get the global objectives:

- Volcanic hazard assessment based on probabilistic techniques, and eruption forecasting.
- High resolution seismic imaging of volcanic structures.
- Real-time observations and measurements.

Task 1. Estimation of the volcanic hazard based on probabilistic techniques, and eruption forecasting

UR coordinating: W. Marzocchi (INGV, Roma 1)
UR participating: S. Falsaperla (INGV Catania) , R. Campanini (Univ. Bologna), L. Crescentini (univ. Salerno)

This task is mainly focused on developing innovative techniques to estimate quantitatively the long- and short-term volcanic hazard. WP1.1 is mainly devoted to develop probabilistic tools to merge information provided by theoretical models, past geological/historical data, and monitoring observations; WP1.2 aims to identify precursors of volcanic activity on different time scales, by analyzing with innovative techniques monitored volcanic eruptions. WP1.3 is focused on improving the knowledge of the stress/deformation changes in volcanic areas.

WP1.1: Probabilistic tools to assess short- and long-term volcanic hazard

We propose to implement and to improve the probabilistic method proposed by Marzocchi et al. (JGR 2004) based on the Event Tree (ET) scheme. ET is a powerful quantitative tool that estimates the probability of all the relevant possible outcomes of a volcanic crisis, and, in general, it quantifies VH and risk. The most important improvement is relative to the introduction of the Fuzzy Logic to overcome all the technical, practical, and theoretical problems raised by the use of "rigid" thresholds at the nodes. For instance, the passage to a quiet state to a state of unrest (node 1 of ET) is sharp depending on the overcoming of a threshold for one or more selected parameters. The Fuzzy Logic allows a more gradual transition from one state to the other, replacing the single threshold with a more appropriate interval of values. Another issue to be improved may be the set of probabilistic rules used to merge the monitoring data with past data and theoretical models, and to evaluate the epistemic and aleatoric uncertainties. The implementation of the models is mainly related to the design of a software tool to visualize the outcomes of ET. We plan to design the code for end user with different technical backgrounds. The software code will replace the usual "hazard maps", since it provides an answer for a complete set of possible queries, from the probability to have a generic or specific kind of eruption in the next month, to the probability map of lahars, pyroclastic flows, or tephra for some specific kind of eruption or for a weighted average of all possible scenarios. The code also furnishes a visual representation of the uncertainties of volcanic hazard assessment. In general, this tool allows probabilities to be continuously updated, and therefore both the long- and short-term VH to be estimated. In particular, the long-term VH assessment (years to decades) is usually estimated only from past data it allows different kinds of hazards (volcanic, seismic, industrial, floods, etc.) in the same area to be compared, which is very useful for cost/benefit analysis of risk mitigation actions, and for appropriate land-use planning and location of settlements. In contrast, monitoring on mid- to short-time scales assists with actions for immediate vulnerability (and risk) reduction, for instance through evacuation of people from danger areas.

WP1.2: Precursory patterns at different time scales

We will develop quantitative tools to evaluate volcanic hazard focusing on seismic signals, as they are recorded in several volcanic areas and are excellent markers of changes within the volcano feeder. We have two main targets: first, we will analyze multivariate seismic databases of some monitored recent eruptions in order to recognize possible seismic precursors, and to identify possible patterns indicating the magnitude (VEI) of the impending event. At this aim, we will use a Support Vector Machine (SVM) classifier that is proved to be one of the best tool for a large variety of quite different fields, such as computer-aided diagnosis, gene classification, industrial processes, video surveillance, face detection in digital images, etc. We will also focus our attention on detecting the seismic variables which are the most important ones in order to correctly forecast a volcanic eruption. This problem will be addressed by means of a feature reduction technique known as a Recursive Feature Elimination (RFE) in collaboration with a Genetic Algorithm (GA): the classification performance will be explored recursively eliminating some of the less discriminant seismic variables according to the cost function of SVM, thus ending up with a restricted set of seismic variables. This reduction is very important in practice, because it may lead to a faster analysis of seismic signals during unrest. Our second target is the application of the Bayesian Belief Network (BBN) technique to structured information stemming from monitoring system combined with: geostatistical analysis and stochastic methods contained in the Deducing Eruptions of Volcanoes In Near Future program (Jaquet et al. 2005), Hidden Multi-state Markov models (Aspinall et al. 2005), Dynamical Systems parameters (Carniel et al. 2003), Material Failure Forecasts (Ortiz et al. 2003), or other multivariate time series statistics. Accommodating the various strands of evidence - from the classification and characterization of seismic signals to statistical data and results of the above listed methods - into the BBN, we will develop an integrated tool which, by indicating probabilistically the progression of state of the volcano unrest, may be used to support alert level decisions. To review precedents, the integrated analysis method will be applied and "tuned" on basaltic volcanoes with persistent activity like Mt. Etna and Stromboli, using past and recent eruptive events, for which continuous data are available. Successive near real time applications for monitoring will then be possible. We will also test applications to volcanoes like Soufriére Hills, Montserrat and Tenerife, Spain.

WP1.3: Mapping and monitoring stress/deformation changes in a volcano

The inversion of geodetic and seismic data is intrinsically nonlinear and results in cost functions with a rough landscape and several local minima. Local optimization techniques can fall into a local minimum, which depends strongly on the starting model. Among the global optimization techniques, we have used ASA (adaptive simulating annealing) to invert geodetic and seismic data for the sources of strong Italian earthquakes occurred last century. Other researchers have used GA (genetic algorithm) to determine the parameters of a volcanic intrusion. As global optimization techniques require to solve many forward problems, time-consuming techniques like 3D finite-element modeling can not be integrated in the inversion codes, but can be used to generate synthetic data sets to test them. On the other hand, it is unrealistic to model the magma chamber as a point source of volume change and a dike as an opening-mode dislocation, assuming that the earth is a homogeneous, isotropic, elastic half-space. We propose to develop two numerical codes for the inversion of geodetic and seismic data and check their feasibility for alert systems. The two codes will use two different optimization techniques, based on ASA and GA, to reinforce results. Besides taking into account the possibility of faulting, we will compute ground deformation and gravity changes using an elasto-gravitational layered Earth model, including a topmost water layer to calculate sea level changes, and a spherical volcanic intrusion. Possible dike intrusion will be modeled as a rectangular tensile fault in a layered earth, using ad hoc variants of the codes by Pollitz (1997) and Wang et al. (2003), originally developed for calculating coseismic deformation. In this case we will estimate the zeroth-order gravity effects due to uplift, water table fluctuation, and density change inside the dike.The inversion codes will be calibrated using synthetic data sets (which we will generate by finite-element modeling) and tested using data from the Campi Flegrei area, which is presently monitored by means of seismic and ground deformation networks and three high-sensitivity Sacks-Evertson dilatometers (installed in 2004), as well as the Monserrat and Long Valley volcanic areas.

Task 2. High resolution seismic imaging of volcanic structures

UR coordinating: A. Zollo (Univ. Napoli, Federico II)
UR participating: J. Virieux (Geoscience Azur), E. Priolo (OGS), A. Piersanti (INGV, Roma 1), F. Bianco (Roma 1).

This task is devoted to investigate, develop and apply innovative tools for a refined seismic imaging of the volcanic structure, which uses the whole waveform amplitude information retrievable on seismic data (arrival times and amplitudes of primary and reflected/converted phases). The rugged model of the volcanic structure can be estimated by seismic reflection methods adapted to work in highly heterogeneous media and non-standard acquisition lay-outs. Rock physical parameters will be studied at the seismological scale by inverting the tomographic images using the medium effective theory, as well as modeling amplitude variation with offset of reflected/converted arrivals. Numerical simulations of the seismic wave-field in a heterogeneous, anisotropic, anelastic medium will allows to analyze the effects of medium complexity on seismic waveforms and calibrate tools for imaging velocity discontinuities, spatial variation of anisotropy and anelastic attenuation parameters. Techniques for the measurement of time and spatial variation of anisotropy/attenuation parameters from local earthquake seismograms will be developed and tested using real and synthetic data.

<u>WP2.1: Reflection seismics in strongly heterogeneous media: application to the detection / modeling of interfaces beneath volcanoes</u>

1/ Processing and analysis of seismic reflection data acquired in unconventional lay-out geometries, global offset ranges and heterogeneous structure environment.

It is proposed the development of methods for move-out and stack(semblance) analysis of reflected and converted arrivals in 2D/3D media which includes the design of 'ad hoc' time and frequency/wavenumber filters able to remove multi-path and coherent noise signals from record sections. It will be investigated the implementation of techniques for the estimate of stack velocity models (based on tomographic models) in lateral heterogeneous structure to be used for the velocity analysis of global-offset data.

2/ Reflector morphology from modeling/migration of reflected/converted phases for global offset data. We propose the development and implementation of a 2D/3D technique for reconstructing the reflector morphology based on depth migration/modeling of reflected/converted arrivals and an 'a priori' knowledge of the heterogeneous background velocity medium. The technique operates on active seismic data, acquired on volcanoes in unconventional lay-outs and is able to work in presence of strong lateral velocity gradients. The method will be based on dynamic ray tracing for heterogeneous velocity models. The possibility to export the technique to passive seismic data acquired by a local network will be also explored.

3/ Converted phases analysis from local earthquake seismograms

Considering this smooth recovered velocity structure, we shal perform scattering analysis for oriented scatterers inside the medium. These oriented points might help us to draw a geological interpretation of the subsurface beneath a volcano. Converted phases will be identified and travel-times will be picked for stacking the converted phase energy. By introducing this new data set, one may hope to improve the resolution of the background model, especially in volcanic zones where complexity is expected.

4/ Amplitude waveform inversion

Linearized waveform inversion might even go further especially for initial waveforms in order to improve our model reconstruction. Only 2D investigation wil be performed taking into account the rather numerical intensive task of the forward modeling. We shall design a tool for this optimization which expect the initial model to be nearby the final one.

<u>WP2.2: From tomography/reflection seismic images to rock physical properties and lithology</u>

1/ Characterization of impedance contrasts at discontinuities in a volcanic structure.

The measurement of amplitude variation of the reflected/converted wave field vs offset allows for investigating the physical properties of the reflecting body by modeling the impedance contrast at the interface. A generalization of this approach to earthquake and active seismic data collected in volcanic area, would require refined source location and mechanism estimations, in addition to an adequate waveform amplitude modeling which accounts for lateral elastic/anelastic medium heterogeneities. We propose the development of a technique for the estimation of the impedance contrast at buried interfaces beneath volcanoes (basement top, magma chamber top) to be used for a physical/lithological characterization of the seismic discontinuity. The amplitudes of principal and secondary (reflected/converted) phases will be computed through a multi-phase seismogram based on the ray-theory.

2/ Retrieval of rock physical parameters from tomographic images.

We shall investigate our to extract information from seismograms in complex zones as volcanic structures. In order to do so, we must design specific tools for first-arrival delayed-time tomography in 3D smooth heterogeneous medium.

We must combine accurate travel-time estimator (Podvin & Lecomte Finite-Difference Eikonal solver) with iterative LSQR matrix inversion technique. We shall introduce Fresnel zones in our tomographic tool for improving resolution. Volcanic rocks are complex with at least two phases at small scales (Foward biphasic formulation). We shall introduce effective medium theory to model this complexity. We shall calibrate these parameters on measured data on rock samples collected in wells through laboratory experiments under well-controlled pressure and temperature. This forward tool will be the kernel of our interpretation in term of rock physics. Recovered seismic velocity images will be interpreted in terms of rock properties by using a simple grid approach which will scan potential values of acceptable rock parameters. This extraction of rock parameters must both reconstructed velocity structures and therefore will be compatible with travel-time data. This interpretation tool will help us to understand what kind of rocks we may expect at depth inside a volcano.

WP2.3: Realistic simulation of volcanic earthquake wave motion

The objectives of this WP will be pursued by two independent RUs through different techniques. The first one will perform the simulations by means of an improved version of the 3D seismic wave field simulation code developed by the same RU. The software is based on the staggered-grid Fourier pseudo-spectral scheme which, using a coarser sampling of the spatial domain, allows the accomplishment of large scale simulations on massively parallel supercomputers. The existing code, written in Fortran 90 with MPI protocol, will be improved in order to account for both medium viscosity and anisotropy in the elasto-dynamic equation and to solve the seismic wave propagation accurately also in the presence of sharp impedance contrasts and irregular topography. Volcanic earthquake sources with arbitrary geometry, size and mechanism will be considered. The reciprocity principle will be exploited in the computation of the Green's functions to simulate a large number of source points. The simulations will be performed using a set of kinematical source models described by space-time functions consistent with the state of the art knowledge of the volcanic seismic sources (fluid-filled crack models). The structural models to be used as input for the simulations will be build up using the Gocad commercial software. The output will consists in snapshots of the seismic wave field as well as in time series collected by arrays of receivers at surface. The maximum effort will be put in pursuing not only a qualitative but also a quantitative reproduction of the volcanic earthquakes, in order to provide a tool for the refinement of the interpretation of the seismic observations in terms of the activity of magmatic systems.

The second RU will develop and modify the Tromp original SEM (Spectral Elements Method) code in order to make it suitable for extremely small scale applications. Then, it is planned to use the Etna and Vesuvio topographic and tomographic models as an input for the modified SEM code in order to simulate the complete wave field produced by an arbitrary volcanic earthquake source in a heterogeneous, anelastic, anisotropic 3D structure. One of the major achievements of SEM approach is the possibility of considering a complete anisotropy of the medium. Therefore, the SEM could be used to test if the shear-wave splitting may become an important indicator of volcanic activity. After modifying it, we plan to run the SEM code both at Caltech and in the parallel linux cluster implemented at INGV by the RU (Hydra). Presently, the SEM code is optimized to run in 32 bit architectures. At INGV we are planning to start the test of 64 bit architectures. The MPI optimization of the SEM code for 64 bit architectures will be one of our goal for the second year of the project. This development would allow us to simulate wavefield with a greater high frequency content.

WP2.4: Estimation of anelastic attenuation and anisotropy parameters

In the first year of the project the attenuation studies will be addressed to the following activities: i) development of a new tomographic inversion technique based on the linearization of the Zollo and de Lorenzo (JGR., 2001) method; ii) implementation of a new technique of Rayleigh waves inversion, based on the semblance among synthetic and observed waveforms, to infer the 1D anelastic Qp and Qs structure of surface layers from high resolution seismic shots; iii) formulation of a Bayesian method to jointly invert P polarities and P pulse widths to obtain source and Q parameters; iv) development of a technique to model P body waves with different rupture velocity time histories and Q models. In the same period the studies on anisotropy will be addressed to the following activities: i) definition of quantitative criteria for automatic data selection and quality detection of splitting measurements; ii) development of a methodology to measure both the splitting parameters simultaneously in a (quasi)automatic way; iii) development of an array technique to measure the splitting parameters; iv) accurate definition of the measure errors on both the splitting parameters.; v) individuation of the spatial (depth and lateral) extent of the crustal anisotropy in some test areas (possibly Vesuvio/Etna).; vi) definition of the fracture criticality level for the test areas. In the second year of the project the attenuation studies will be addressed to the following activities: i) application to synthetic and real cases (Flegrei, Serapis, Etna, Vesuvio) of the techniques implemented in the first year. In the same year, the studies on anisotropy will be addressed to the following activities: i) time variation of crustal anisotropy in some test areas (possibly Vesuvio/Etna); ii) Quantification of the average pore pressure from splitting measurements.

Task 3. Real-time observations and measurements

UR coordinating: G. Iannaccone (INGV-OV)

UR participating: M. Martini (INGV-OV), G. Vilardo (INGV-OV), G. Romeo (INGV-Roma 1), L. Lodato (INGV-Catania)

The task 3 aims to provide new tools of real-time analysis of seismic and thermal monitoring data, an to design and test of a prototype, sea-bottom multi-parametric station integrated to an on-land existing monitoring network. The real time seismological monitoring needs different analysis techniques for covering the wide manifold of seismo-volcanic signals. Automatic techniques for real-time detection, location and moment tensor estimation of seismic events (short-period, long- and very long- period signals) will be developed and made able to work in 3D heterogeneous volcanic structures. Concerning the experimentation of prototypes for data acquisition in hostile environments it will be developed and tested a sea bottom seismic station with real time transmission connected to the monitoring system of Neapolitan volcanic area. New instruments for thermal monitoring will be conceived and tools to analyze thermal images in near real-time.

<u>WP3.1: Real-time estimation of earthquake source parameters</u>

Major efforts will be devoted in 2005 for the adoption of 3D velocity models in hypocenter location. First existing 3D tomographic models will be collected and eventually merged together and adapted to fit region of interest around Neapolitan volcanic areas. Then the whole existing database (together with the new data from 1984 data reprocessing) will be relocated using a non-linear EDT approach. In a second stage this technique will be implemented as a standard in automatic location procedure of the monitoring system.

A seismological multiparametric database, containing information as tremor amplitude, wavefield spectra, polarization, array slowness estimates and raw waveforms, will be developed and joined together with the pre-existing hypocenters database. The new system will be designed according to the experience acquired on the Stromboli data analysis (EOLO system). The seismic data contained in this global database, coming from different subnetworks, will be stored adopting standard data formats, useful for data exchange with other monitoring centers. The system will be able to automatically recover data possibly lost during network downtimes. All of the data, both stored and real-time, will be available to the users with a common and coherent interface.

In 2006, two more tools will be added to the Neapolitan volcanic area monitoring system. The first will be a neural network based seismic discrimination system, based on an algorithm has shown to be efficient in Vesuvius area in discriminating true earthquakes from thunders and artificial explosions. The second is a moment-tensor inversion system based on non-linear search algorithms. The access to the whole database will be implemented using an user-friendly web interface that will allows an efficient check of the temporal variations, the cross-correlations and the statistical analysis of the seismic source parameters.

WP3.2: Design and test of a prototype, sea-bottom multi-parametric station integrated to an on-land existing monitoring network.

The main objective of the two years project is to develop and test an OBS with real time transmission connected to the monitoring system of Neapolitan volcanic area. In the frame of the PON project an OBS with standard seismological instruments will be acquired and modified to monitor in real time data collected at the sea bottom. The instrument will be connected by means of a cable to an existing large floating platform (fishing farm). A free-wave radio provides I.P.-based telemetry between the platform and a control center in order to transfer in real time the seismic information recorded at the sea bottom. On the platform a power supply system with solar panels and rechargeable batteries will provide the necessary energy for continuous operation of the sea bottom instruments. The platform operate in the Gulf of Pozzuoli at about two miles offshore where depth of the sea is about 100m.

The first year will be devoted to:

- identify the OBS model to acquire
- define the technical specifications for the cable connection
- define the technical specification of the cable
- propose solutions to connect cable to the floating platform
- test the complete system (OBS+cable+radio transmission) in laboratory
- install the necessary equipments on the platform
- install the OBS on the sea bottom and test all components
- plan and develop of an electronic prototype data logger system for OBS case equipment (OB-GILDA)

The activity of the second year will be:

- testing of OB-GILDA
- to experiment the acoustic link developed by WASS in the frame of the PON project
- to develop and test a software management of the acquisition system. This software will be able to request any time slice of interest, regardless of when the data were recorded. The time slices will be defined on the basis of a daily/weekly catalogue published by UF Centro di Monitoraggio of OV-INGV; and by an event list generated by the data logger. All digitized data could be also telemetered to the control center.

For a practical application we will evaluate the possibility of integrating the undersea system on Campi Flegrei or Stromboli monitoring networks.

WP3.3: Surface thermal imaging

The work inside this WP consists of different activities, ranging from the conception of new instruments for thermal monitoring, and tools to analyze thermal images in real-time (or near real-time). As regards the first activity, we plan to improve the design of the thermal head, the production of two arrays, and the permanent installation of one of them in a site (i.e., Campi Flegrei) for a continuous thermal gradient measurement and to allow the calibration of the existing IR imaging system. As regards the second objective, the planned activities will involve i) the collection of a comprehensive database of TIR images to characterize the background level of the thermal emissions at Vesuvius, Campi Flegrei; ii) TIR images calibration to account for absorption and atmospheric parameters variations due to normal seasonal variations and local weather conditions; iii) complete automation of the processes of extraction from the TIR image data of numerical parameters; iv) development of programs for real-time data analysis and information visualization for the continuous monitoring of the space-time evolution of both the temperatures field and the associated geochemical and atmospheric parameters; v) development of new quantitative computational advanced methods to allow near real-time analysis of thermal imagery for estimation of lava effusion rates during volcanic crises. Part of the planned work on these issues will be devoted to apply and verify the methods to real cases.

Deliverables list

Task 1. Estimation of the volcanic hazard based on probabilistic techniques, and eruption forecasting: - Implementation of the Event Tree scheme including Fuzzy Logic - Visualization and computation code to estimate volcanic hazard - Development of quantitative tools to analyze multivariate seismic database in order to recognize potential precursory patterns of volcanic eruptions - A software pattern recognition package, aimed to find precursory patterns of volcanic eruptions - Definition of probabilistic rules to quantify short-term volcanic hazard - Results from finite element modeling of ground deformation and gravity - Inversion codes for near real-time applications to study ground deformation and gravity.

Task 2. High resolution seismic imaging of volcanic structures: - Development of methods for processing and analysis of seismic reflection data and converted phases analysis from local earthquake seismograms - Testing (application to synthetic/real data sets) of methods for determining reflector morphology from modelling/migration of reflected/converted phases and for linearized amplitude waveform inversion - Development of methods for the characterisation of impedance contrasts at discontinuities in a volcanic structure and retrieval of rock physical parameters from tomographic images - Testing (application to synthetic/real data sets) of methods for the characterisation of impedance contrasts at discontinuities in a volcanic structure and retrieval of rock physical parameters from tomographic images - Implementation of Komatish and Tromp SEM code to volcanic application - Simulation of the complete wave field produced by volcanic earthquake sources (double- and not double couple sources, low frequency events, tremor,…) in heterogeneous, anelastic, anisotropic 3D structures - Database of synthetic wave field - Development and implementation of Fortran Codes to infer 3D Anelastic attenuation and rheological models of volcanic structures - Development and implementation of Fortran, Matlab and Mathcad Codes to measure space and time variation of the anelastic attenuation and anisotropy properties of the volcanic rocks - Results from the application of the methodologies to real and synthetic data and, consequently, definition of 3D Anelastic attenuation and rheological models.

Task 3. Real-time observations and measurements: - Developments of techniques aimed at automatic classification and discrimination of seismic signals - An integrated multiparametric seismic database - Real-time estimation of earthquake source parameters in a volcanic area (Earthquake location, magnitude/moment, moment tensor) - System Architecture design of OBS - Implementation and test in a volcanic area - Continuous real-time surface thermal measurements at the Vesuvius and Solfatara sites, and background assessment – Database of TIR images with associated parameters, and of gradiometer arrays measurements - Integrated report on the implementation and test in a volcanic area of data acquisition, analysis and modelling of surface thermal images - System Architecture design of gradiometer arrays.

PROJECT V4 – NEW TECHNIQUES

TABLE MAN/MONTHS

U.R	Institutions	Principal Responsibles	Task1 Coordination	Task2 Probabilistic techniques for volcanic hazard	Task3 High resolution seismic imaging	Task4 Real time observations and measurements	Mesi p. cofin.	Mesi p. rich.
UR-1	INGV-Rm1	Marzocchi	@	@			17	
UR-2	INGV-CT, Soc. Aspinall (UK), UniUd, Colenco Baden (CH), Univ. Leeds (UK), NIIZK St. Petersburg (RU)	Falsaperla, Aspinall, Carniel, Neuberg, Psenichny		@			79	
UR-3	UniBo	Campanini		@			24	24 (UniBo)
UR-4	UniSa, INGV-Rm, CIW (USA)	Crescentini, Amoruso, Scarpa		@			34	24 (UniSa)
UR-5	UniNa, UniSan	Zollo, De Matteis	@		@		24	24 (UniNa)
UR-6	Geosciences Azur (FR)	Virieux, Vanorio			@		48	
UR-7	OGS Tri	Priolo			@		8	24 (OGS)
UR-8	INGV-Rm1, Caltech Inst. (USA)	Piersanti			@		34	
UR-9	INGV-OV, UniBa, INGV-CT, Univ. Edinburgh (UK)	Bianco, Del Pezzo, De Lorenzo			@		97	12 (assegno di ricerca INGV-OV)
UR-10	INGV-OV, UniSa, USGS (USA)	Martini, Chouet				@	35	
UR-11	INGV-OV, UniNa	Iannaccone				@	50	12 (Assegno INGV)

UR-12	INGV-Rm1	Romeo, Quattrocchi				@	17	
UR-13	INGV-OV	Vilardo, Chiodini				@	24	
UR-14	INGV-CT, Univ. Hawaii (USA), Univ. Alaska (USA), Cambridge Univ. (UK)	Lodato, Harris				@	24	
Totale							515	120

PROJECT V4 – NEW TECHNIQUES

Table RU and related funding request

N. UR	**Istituz.**	**Resp UR**	**Personale**		**Missioni**				**Consumi servizi**		**Inventariabile**	
					Italia		**Estero**					
			2005	**2006**	**2005**	**2006**	**2005**	**2006**	**2005**	**2006**	**2005**	**2006**
UR-1	INGV-Rm1	Marzocchi			2000	3000	3000	3000	13000	13000	13000	10000
UR-2	INGV-CT	Falsaperla[1]			2000	2000	3000	3000	32000	32000		
UR-3	UniBo	Campanini	16000	16000	1000	1000	1000	1000	4000	4000	2000	2000
UR-4	UniSa	Crescentini	19000	19000	1500	1500	2500	2500	3000	4000	3000	2000
UR-5	UniNa	Zollo[2]	38500	38500	1000	1000	3000	3000	19800	19800	2500	2500
UR-6	Geoazur	Virieux					12000	12000	14000	14000	4000	4000
UR-7	OGS Tri	Priolo	25300	25300	2000	2000	2000	2000	4700	4700		
UR-8	INGV-Rm1	Piersanti			1000	1000	5000	5000	1000	1000	8000	8000
UR-9	INGV-OV	Bianco			2000	2000	3000	3000	13000	17000	4000	
UR-10	INGV-OV	Martini				2000			4000	7000	20000	
UR-11	INGV-OV	Iannaccone			2000	2000	2000	6000	20000	16000	20000	10000
UR-12	INGV-Rm1	Romeo			2000	6000			21100	2000	3400	
UR-13	INGV-OV	Vilardo			3000	3000	2000	2000	11000	11000		
UR-14	INGV-CT	Lodato			1000	1000	3000	3000	14000	14000		
		TOTALE	**98800**	**98800**	**20500**	**27500**	**41500**	**45500**	**174600**	**159500**	**79900**	**38500**
GRAN TOTALE: 785100												

[1]32000 euros (16000 each year) included under the voice "Consumi e servizi" will be provided to the Univ. of Udine for research activities under the responsibility of R. Carniel.

[2]The cost for personnel (38500 euros per year) corresponds to the full cost per year of a European post-doc researcher (35000 euros) with a "CoCoCo" contract, and includes the costs under the voice "IRAP" which must be covered by the engaging institution.