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MED-SUV 2nd Year Meeting

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Editors: Giuseppe Puglisi, Letizia Spampinato, Danilo Reitano

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Geofisica e Vulcanologia

MEDiterranean SUpersite Volcanoes
MED-SUV

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Letizia Spampinato	Technologist, Member of the Organizing Committee, Project Management
Francesca Bianco	Senior Researcher, Leader of Organizing Committee
Luca D'Auria	Researcher, Member of the Organizing Committee
Agata Sangianantoni	Technologist, Member of the Organizing Committee, Project Management
Enzo Torello	Technician, Member of the Organizing Committee
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Sabrina Tulino	Administrative Office, Member of the Organizing Committee
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Salvatore Mangiagli	Technologist, Member of the Organizing Committee, Web Master

Immagine di frontespizio

Painting of the 1779 Vesuvius eruption. Jakob Philipp Hackert

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Preface

The MEDiterranean SUpersite Volcanoes (MED-SUV) is a FP7 project born under the European Community call "ENV.2012.6.4-2 "*Long-term monitoring experiments in geologically active regions of Europe prone to natural hazards: the Supersite concept"* - FP7-ENV-2012-two-stage – of 20 July 2011. MED-SUV, which started on 1 June 2013, is just on its third and last year of activities. The project has focused on pushing forward the concept of the Geo-Supersites promoted by GEO-GEOSS, by carrying out research and technological development at two of the main hazardous European volcanic areas – Mt. Etna and Campi Flegrei/Vesuvius.

MED-SUV is structured in 8 operational Work Packages (WPs) among which WP1 deals with the project coordination and management and WP8 with the dissemination of the project outcomes. The other 6 WPs are involved in RTD activities, and in particular WP2 and WP3 are dedicated to the design and implementation of new instrumentation and of the project e-infrastructure, respectively. WP4 and WP5 are where the volcanic research activities are carried out at Campi Flegrei/Vesuvius and Mt. Etna, respectively. WP6 is fully dedicated to volcano hazard modelling. WP7 represents the framework in which the novel achievements are validated by tests carried out at two other European volcanic systems, i.e. Piton de la Fournaise and Azores.

Throughout the second year, many of the activities foreseen in the project work plan were carried out including the implementation of the architecture of an e-infrastructure for data access, development of new tools and instrumentation for volcano monitoring, research experiments for better understanding of the volcanic feeding systems and eruptive activity, data analysis and modelling for volcanic hazard assessment, and dissemination activities to promote the project results among the scientific community and to foster people awareness of volcanic phenomena.

At the present, the MED-SUV consortium has already moved on with the activities scheduled for the third year. Indeed, aside the finalization of the activities started in the previous two years, the main challenge of the community consists on the formulation of the best strategy for ensuring the broadest dissemination of the project outcomes. This aim includes MED-SUV data sharing and data protection by well-established data policy principles and intellectual property definition, as well as the design of a robust strategy for the long-term sustainability of results, such as the project e-infrastructure.

In order to discuss, share, and plan the results achieved and the future perspectives, the MED-SUV consortium is convening for its yearly appointment. Differently from the last July, this year the meeting is hosted in Naples, the town that more than the others, is associated with volcanic power and destruction. The Neapolitan volcanoes, indeed, signed the birth of Volcanology. In fact, from Capo Miseno (northern border of the Campi Flegrei caldera), Pliny the Younger described the 79 AD Mt. Vesuvius eruption, thus providing the first scientific report of a volcanic eruption, which is at the base of many studies of this volcano and of the plinian eruptions even in the current research.

Project Leader
Giuseppe Puglisi

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WP1

Posters

Access Rules for MED-SUV e-Infrastructure

Agata Sangianantoni[1], Giuseppe Puglisi[2], Letizia Spampinato[2], Luca D'Auria[1]

[1]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Napoli - Osservatorio Vesuviano, Napoli, Italy*
[2]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania - Osservatorio Etneo, Catania, Italy*

MED-SUV is implementing an e-Infrastructure which is making available both Earth Observation and "in situ" data at the Italian Supersite and at a global level contributing to regional, national, European and global development in open, interconnected, data-driven volcanic science research. The implementation of the e-Infrastructure requires the clear need to set up Access Rules in order to govern the overall process from Registration to Download. A clear balance between the needs of data providers as well as users must be achieved and to do so effectively close synergies between WP1 Management and WP3 Data Sharing, Integration and Interoperability are being established. Access Rules are conceived to govern the electronic application form, the legal acceptance of terms and conditions, the liability issues, the confidentiality requirements and the licensing method that will be arranged. We believe that the implementation of Access Rules, properly shared and agreed among partners, will give significant benefits to both data providers and users reaching a clear understanding of the use and exploitation of data.

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WP2

Talks

The prototype of the automated high-resolution InSAR volcano-monitoring system

Tanvir A. Chowdhury

DLR - Deutsches Zentrum für Luft- und Raumfahrt, Köln, Germany

In recent past, remote sensing techniques have become established in operational forecasting, monitoring and managing of volcanic hazards. Due to the weather and illumination independence, space-borne synthetic aperture radar (SAR) plays a critical role in operational volcano monitoring. The capability of SAR for observing volcanoes is further enhanced by the ability of interferometric SAR (InSAR) to measure eruption-related surface deformation signals. The Piton de la Fournaise volcano (Reunion Island, France) is one of the most active basaltic shield volcanoes in the world. Most historical eruptions have originated from the summit and flanks of Dolomieu. Observatoire Volcanologique du Piton de la Fournaise (OVPDLF) reported on 29 September 2010 that earthquakes were located at the base of the volcano, and inflation was noted particularly on the eastern flank. A significant number of landslides were detected in the crater. A steady increase in the number and magnitude of volcano-tectonic earthquakes from Piton de la Fournaise since 7 October were recorded. During 10-11 October the summit area inflated 3-7 cm and an increase in the number of landslides in the crater was detected. The Alert level remained at 1 ("probable or imminent eruption"). On 14 October, an eruption began near the Château Fort crater, about 1.5 km SE of the Dolomieu crater rim, continued during 19-25 October. During 20-21 October small lava fountains fed lava flows that travelled as far as 2 km E and SE. During 22-24 October fountains and gas emissions originated from one vent, and lava travelled ESE. Gas emissions decreased significantly. We applied the InSAR time-series analysis to TerraSAR-X data acquired on both ascending and descending orbits from April 2010 to November 2010. The interferograms are generated from the SAR Satellite based High Resolution Data Acquisition System, which is developed at DLR in the framework of a remote sensing task of MED-SUV project. InSAR time series survey revealed pre-eruptive and post-eruptive deformation signals. The poster focusses on displaying results of the TerraSAR-X System and offers the possibility to discuss the distribution, use and formatting.

New space-borne monitoring techniques: Synthetic Aperture Radar (SAR) Doppler anomalies during volcanic eruptions and the use of Landsat 8 to extract the gas/ash Plume Elevation Model (PEM)

Marcello de Michele, Daniel Raucoules

Bureau de Recherches Géologiques et Minières, French Geological Survey, Orleans, France

We use multiple SAR data to investigate Doppler anomalies in the SAR signal occurring during volcanic eruptions. In Synthetic Aperture Radar, variations in the Electro Magnetic Waves travel time results in a change in the Doppler frequency that adds up to the one that is naturally generated by the relative motion between the platform and the ground targets. Within the SAR system, frequencies modulations control the image focusing along the two fundamental SAR directions, the azimuth (i.e. the platform motion direction) and the range (i. e. the sensor looking direction). During the synthetic aperture process (the so called image focusing) a target on the surface is seen along different paths. In standard focusing processing it is assumed both that ground targets are stationary and that between the sensor and the target the medium is the vacuum or a totally homogeneous medium. Therefore, if there is a significant path delay variation along the paths to a specific target this can result either in image defocusing or in pixel misregistration or both. We apply a sub-aperture cross correlation algorithm on Single Look Complex data; we measure any pixel misregistration between two sub-looks of the same SAR acquisition. If a pixel shift occurs, it means that the expected radar wave path has been lengthened (or shortened) during the time when ground surface scatterers were illuminated by the sensor radiation either by a ground feature velocity (e. g. water flows, vehicles) or it is refracted by a strong medium discontinuity in the air (volcanic ash plume?). If a Doppler history anomaly is detected by the sub-aperture cross correlation, we try to explore whether it is possible to distinguish between signal delays due to the presence of a volcanic ash plume and the signal delays due to other volcano-related phenomena (such as lahars, lava flows velocity, ice melts, ocean currents induced/modified by lahars discharges), or simply non volcano-related natural phenomena such as ocean currents and river flows. We focus on Mount Etna 2011 lava fountain episodes covered by one Radarsat-2 SAR image. Then we focused on the largest eruption producing an ash plume in the last decade, the 2010 Eyjafjallajokull eruption in Iceland by using a selected set of data from the German Space Agency (DLR) TerraSAR X sensor.

As a new monitoring technique, we developed a method to derive the volcanic gas/ash Plume Elevation Model (PEM) from optical satellite imagery from Landsat 8. As the plume is rapidly moving, conventional satellite based photogrammetric height restitution methods fail as the epipolar offset due to plume displacements adds up to the one generated by the stereoscopic view. Our method is based on a single satellite pass. We exploit the short time lag and resulting baseline that exist on Landsat 8 between the Multi-Spectral and the Panchromatic bands to jointly measure the epipolar offsets and the perpendicular to the epipolar (P2E) offsets. The first are proportional to plume height plus the offsets due to plume velocity in the epipolar direction. The second are proportional to plume velocity in the P2E direction only. The latter is used to compensate the effect of plume velocity in the stereoscopic offsets by projecting it on the epipolar direction assuming the plume direction as known, thus improving the height measurement precision. We apply the method to Landsat 8 data taking into account the specificities of a wisk-broom sensor. We focus on the Holuhraun 2014 fissure eruption (Iceland). We validate our measurements with ground based measurements. The method has potential for routine measurements of volcanic plume height/velocity retrieval. The method can be applied both to other wisk-broom sensors such as the incoming ESA Sentinel 2 and potentially to other push-broom systems such as the CNES SPOT family. We plan future applications on the study of the Etna plume height.

Application of the new data logger to the acquisition of multi-parameter geophysical data in Solfatara volcano

Massimo Orazi, Rosario Peluso, Flora Giudicepietro

Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Napoli - Osservatorio Vesuviano, Napoli, Italy

We have improved the characteristics of GILDA digital recorder, developed at Osservatorio Vesuviano (INGV). to realize a robust user-oriented acquisition system for multi-parameter geophysical monitoring. We have designed and implemented new capabilities concerning the use of the low rate channels to get data of environmental parameters of the station. We also improved the stand-alone version of the data logger. The stand-alone version can be especially useful for scientific experiments and to rapidly upgrade permanent monitoring networks, in case of volcanic crises. Furthermore, the local storage can be used as back-up for the monitoring systems in continuous transmission, in case of failure of the transmission system. Some firmware changes have been made in order to improve the performance of the instrument. In particular, the low rate acquisition channels were conditioned to acquire internal parameters of the recorder such as the temperature and voltage. A prototype of the new version of the logger has been installed at Campi Flegrei for a experimental application. Our experiment is aimed at testing the new version of GILDA data logger in multi-board configuration for multi-parametric acquisitions. A second objective of the experiment is the comparison of the recorded data with geochemical data acquired by a multi-parametric geochemical station to investigate possible correlations between seismic and geochemical parameters. The target site of the experiment is “Bocca Grande” fumarole in Solfatara volcano. By exploiting the modularity of GILDA, for the experiment has been realized an acquisition system based on three data loggers for a total of 12 available channels. One of GILDA recorders is the Master and the other two are Slaves. The Master is responsible for the initial configuration of the GPS receiver for timing data. This allows you to use one GPS receiver and optimize power consumption. The acquired data are locally stored on a memory card. A software interface, that we developed, allows easily extracting and converting data to standard seismological format.

Design and characterization of a tri-axial FBG strain sensor for volcano monitoring

Nicolò Beverini[1], Massimo Calamai[1], Daniele Carbone[2], Giorgio Carelli[1,3], Nicoletta Fotino[3], Francesco Francesconi[3], Salvo Gambino[2], Renzo Grassi[3], Alfio A. Messina[4], Enrico Maccioni[1], Mauro Morganti[5], Fiodor Sorrentino[3,6]

[1]*Dipartimento di Fisica, Università di Pisa, Pisa, Italy*
[2]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania - Osservatorio Etneo, Catania, Italy*
[3]*Marwan Technology Srl, Pisa, Pisa, Italy*
[4]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Roma 2, Roma, Italy*
[5]*Istituto Nazionale di Fisica Nucleare, sezione di Pisa, Pisa, Italy*
[6]*Istituto Nazionale di Fisica Nucleare, sezione di Genova, Genova, Italy*

Fiber Bragg Grating (FBG) sensors have emerged as cost-effective tools for monitoring, diagnostics and control in civil engineering. However, while these sensors would have a potential impact in geophysics, very limited literature exists in the geophysical field. In order to study earthquakes and volcanoes, the measurement of crustal deformation through strain sensors is crucial in geophysical applications. Stress and strain changes at volcanic areas are recognized among the best indicators of changes in the activity of the system, and its possible evolution towards critical stages. Conventional methods consist of extensometers and interferometers installed underground: but such sensors are large in size (from several tens to hundreds of meters in length) and thus of difficult installation. In the last few decades FBG sensors appeared to be among the most promising tools for stress-strain monitoring in geophysics. Among the others, the main advantages of FBG sensors in geophysics include the low cost, the small size, the easy implementation of large arrays covering a wide frequency range and the immunity to harsh weather conditions. We developed an FBG strain sensor in the framework of WP 2 (New monitoring and Observing systems) of the MED-SUV project. The systems performances are tailored to suit the requirements of volcano monitoring, with special attention to the trade-offs among resolution, power consumption, and cost. The system features significantly higher resolution and accuracy in static measurements with respect to previous implementations of the FBG technology to study rock deformations. Moreover, the sensor has been developed in tri-axial configuration. We will present the design and laboratory characterization of the device, in view of field campaigns in the near future.

The use of Etna_NETVIS for rapid mapping of lava flows: test cases on recent eruptive events

Peppe J-V. D'Aranno[1], Roberto De Bonis[1], Maria Marsella[1], Carla Nardinocchi[1], Silvia Scifoni[1], Marianna Scutti[1], Alberigo Sonnessa[1], Wissam Wahbeh[1], Emilio Biale[2], Mauro Coltelli[2], Emilio Pecora[2], Michele Prestifilippo[2], Cristina Proietti[2]

[1]Survey Lab srl Spin Off of Sapienza - DICEA- Università di Roma, Roma, Italy
[2]Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania - Osservatorio Etneo, Catania, Italy

This work is aimed at optimizing the observational capability of the ground-based NEtwork of Thermal and VIsible cameras of Mt. Etna (Etna_NETVIS) by developing a dedicated tool for extracting lava flow maps of known accuracy. As a first step, the analysis of the present geometrical configuration of the network and its possible implementation by deploying mobile stations during emergency phases was conducted. This action will increment the spatial coverage and improve the observation of the most active areas during sin-eruptive processes. The network configuration was designed in a 3D modelling environment that required an updated DEM and the a-priori knowledge of the camera technical characteristics. The second step consisted in the development of a dedicated prototypal tool for automatically pre-processing of large image datasets that allow following the propagation of lava fields. The tool permits to obtain a coherent multi-temporal dataset of orthophotos provided that a reference DEM is available. These datasets are further analysed to extract 2D features describing the lava flow limits that, compounded into a flow evolutions maps, allow to rapidly estimating the advancement rate and the direction of the active lava flows. The developed tool is composed by three different modules: the Orientation Module, that is devoted to camera calibration (internal orientation) and to the estimation of position and attitude of the camera (external orientation); the Image Orthorectification Module, which provides georeferenced and rectified orthophotos at a user selected spatial resolution and coverage; the Feature Extraction Module, a semi-automated procedure that it is used to extract features and for change detection analysis of the multi-temporal datasets.
The prototype tool was tested in simulated and real environments: a test field have been established at INGV-POSEIDON edifice in Nicolosi and at La Montagnola observation site in order to evaluate the spatial and radiometric accuracy of the sensors and verify the internal and external orientation procedure. The overall procedure was adopted to obtain lava flow evolution maps from image datasets acquired from Monte Cagliato station during recent effusive eruptions.

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WP2

Posters

Development and assessment of an automated high resolution InSAR volcano-monitoring system in the MED-SUV project

Tanvir A. Chowdhury, Christian Minet, Thomas Fritz

Remote Sensing Technology Institute, Deutsches Zentrum Luft- und Raumfahrt e.V. (DLR), Wessling, Germany

Volcanic processes which produce a variety of geological and hydrological hazards are difficult to predict and capable of triggering natural disasters on regional to global scales. Therefore it is important to monitor volcano continuously and with a high spatial and temporal sampling rate. The monitoring of active volcanoes requires the reliable measurement of surface deformation before, during and after volcanic activities and it helps for the better understanding and modelling of the involved geophysical processes.

The SAR satellite-based High Resolution Data Acquisition System developed at DLR can add regular SAR-Surveys to the growing data collected from all the in-situ systems and thus contribute to the improvements of the understanding of geophysical processes underlying the volcanic systems of Vesuvius/ Campi Flegrei and Mt. Etna.

Space-borne synthetic aperture radar (SAR) interferometry (InSAR), persistent scatterer interferometry (PSI) and small baseline subset algorithm (SBAS) provide a powerful tool for observing the eruptive activities and measuring the surface changes of millimetre accuracy. All the mentioned techniques with deformation time series extraction address the challenges by exploiting medium to large SAR image stacks. The process of selecting, ordering, downloading, storing, logging, extracting and preparing the data for processing is very time consuming has to be done manually for every single data-stack. In many cases it is even an iterative process which has to be done regularly and continuously. Therefore, data processing becomes slow which causes significant delays in data delivery.

The SAR Satellite based High Resolution Data Acquisition System, which will be developed at DLR, will automate this entire time consuming tasks and allows an operational volcano monitoring system. The automated volcano monitoring system keeps track of their progress, keep all logging updated and prepare reports showing the processing results. Furthermore, the system will deliver specified reports and maps to a database for review and use by specialists. The user interaction will be minimized and iterative processes will be totally avoided.

In this presentation, a prototype of SAR Satellite based High Resolution Data Acquisition System, which is developed and operated by DLR, will be described in detail. The workflow of the developed system is described which allow a meaningful contribution of SAR for monitoring volcanic eruptive activities. A more robust and efficient InSAR data processing in IWAP processor will be introduced in the framework of a remote sensing task of MED-SUV project. An application of the developed prototype system to a historic eruption of 2011 in Mount Etna will be depicted in the last part of the presentation.

Application of the new data logger to the acquisition of multi-parameter geophysical data in Solfatara volcano

Massimo Orazi, Rosario Peluso, Flora Giudicepietro

Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Napoli - Osservatorio Vesuviano, Napoli, Italy

We have improved the characteristics of GILDA digital recorder, developed at Osservatorio Vesuviano (INGV) to realize a robust user-oriented acquisition system for multi-parameter geophysical monitoring. We have designed and implemented new capabilities concerning the use of the low rate channels to get data of environmental parameters of the station. We also improved the stand-alone version of the data logger. The stand-alone version can be especially useful for scientific experiments and to rapidly upgrade permanent monitoring networks, in case of volcanic crises. Furthermore, the local storage can be used as back-up for the monitoring systems in continuous transmission, in case of failure of the transmission system. Some firmware changes have been made in order to improve the performance of the instrument. In particular, the low rate acquisition channels were conditioned to acquire internal parameters of the recorder such as the temperature and voltage. A prototype of the new version of the logger has been installed at Campi Flegrei for a experimental application. Our experiment is aimed at testing the new version of GILDA data logger in multi-board configuration for multi-parametric acquisitions. A second objective of the experiment is the comparison of the recorded data with geochemical data acquired by a multi-parametric geochemical station to investigate possible correlations between seismic and geochemical parameters. The target site of the experiment is “Bocca Grande” fumarole in Solfatara volcano. By exploiting the modularity of GILDA, for the experiment has been realized an acquisition system based on three data loggers for a total of 12 available channels. One of GILDA recorders is the Master and the other two are Slaves. The Master is responsible for the initial configuration of the GPS receiver for timing data. This allows you to use one GPS receiver and optimize power consumption. The acquired data are locally stored on a memory card. A software interface, that we developed, allows easily extracting and converting data to standard seismological format.

Tri-axial FBG strain sensor for volcano monitoring

Nicolò Beverini[1], Massimo Calamai[1], Daniele Carbone[2], Giorgio Carelli[1,3], Nicoletta Fotino[3], Francesco Francesconi[3], Salvo Gambino[2], Renzo Grassi[3], Alfio A. Messina[4], Enrico Maccioni[1], Mauro Morganti[5], Fiodor Sorrentino[3,6]

[1]*Dipartimento di Fisica, Università di Pisa, Pisa, Italy*
[2]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania - Osservatorio Etneo, Catania, Italy*
[3]*Marwan Technology Srl, Pisa, Pisa, Italy*
[4]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Roma 2, Roma, Italy*
[5]*Istituto Nazionale di Fisica Nucleare, sezione di Pisa, Pisa, Italy*
[6]*Istituto Nazionale di Fisica Nucleare, sezione di Genova, Genova, Italy*

We present the development and field test of an FBG strain sensor specifically developed for volcano monitoring; The device has been designed with special attention to the trade-offs among resolution, power consumption, and cost. The system features significantly higher resolution and accuracy in static measurements with respect to previous implementations of the FBG technology to study rock deformations. Moreover, the sensor has been developed in tri-axial configuration. A field campaign was carried out with a preliminary single-axis FBG strain sensor prototype on Mt. Etna, in order to check the system performances in out-of-the-lab conditions and in the hostile volcanic environment (lack of mains electricity for power, strong diurnal temperature changes, strong wind, erosive ash, snow and ice during the winter time), and to determine whether measurable changes are induced across a 1989 fracture system during the paroxysmal phases of Etna's volcanic activity. We found positive correlations between the signal detected by the FBG strain meter and the volcanic tremor detected by a seismic station at Mt. Etna (ESPC). This represented an encouraging result since the installation has been performed on a surface trace where the signal is dominated by thermally induced strain; whereas the final prototype will be installed underground thus the sensitivity of the device to micro tremors will increase.

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WP3

Talks

The MED-SUV multidisciplinary interoperability infrastructure

Stefano Nativi[1], Paolo Mazzetti[1], Fabrizio Papeschi[1], Luca D'Auria[2],
Pier P. Mathieu[3], Fabrice Brito[4], Danilo Reitano[5]

[1]*Consiglio Nazionale delle Ricerche-IIA, U.O.S. di Firenze, Firenze, Italy*
[2]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Napoli - Osservatorio Vesuviano, Napoli, Italy*
[3]*European Space Agency, ESRIN, Roma, Italy*
[4]*Terradue Srl, Roma, Italy*
[5]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania - Osservatorio Etneo, Catania, Italy*

The MED-SUV European project (http://med-suv.eu/) aims to provide datasets and services to support the lifecycle of the volcanic risk management in southern Italy. To this aim it needs achieving the integration of existing components, such as monitoring systems and data bases, novel sensors for the measurements of volcanic parameters, and tools for data analysis and process modelling. Moreover MED-SUV is also a direct contribution to the Global Earth Observation System of Systems (GEOSS; http://www.earthobservations.org/geoss.shtml) as one the volcano Supersite recognized by the Group on Earth Observation (GEO; see http://supersites.earthobservations.org). To achieve its goals, MED-SUV needs to set up an advanced e-infrastructure allowing: (a) heterogeneous data and processing systems to provide and share their resources, and (b) supersite Users to run their workflows and generate significant products. In the second year of activity a first version of the infrastructure has been setup. Based on the approach and architecture described in the "System and gap Analysis" document, released on the first year, an instance of the GI-suite Brokering Framework has been deployed on Amazon Infrastructure-as-a-Service. It has been configured to broker several different data sources including: DLR; INGV-Rome Iris Event; INGV-Rome Iris Station; ESA/TerraDue MEDSUV; UNAVCO; MED-SUV data repository. The architecture and first version of the infrastructure will be presented and demonstrated during the 2nd annual meeting of the MED-SUV project.

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WP3

Posters

Long- and short-term deformation analysis at Mount Etna volcano through the SBAS- DInSAR technique

Antonio Pepe, Susi Pepe, Manuela Bonano, Raffaele Castaldo, Francesco Casu, Claudio De Luca, Vincenzo De Novellis, Michele Manunta, Eugenio Sansosti, Giuseppe Solaro, Pietro Tizzani, Riccardo Lanari

Istituto per il Rilevamento Elettromagnetico dell'Ambiente (IREA), National Council Research of Italy (CNR)

Volcanoes may deform as a consequence of several geophysical processes that evolve at different spatial and temporal scales. In this work, we focus on Mt. Etna stratovolcano and we investigate the relationship between the deformation behaviours related to long- and short-term volcanic processes associated with the ascent of magma. To discriminate between long and short-term effects, we analyse a large Synthetic Aperture Radar (SAR) data archive acquired on Mt. Etna by several satellites over the past 20 years. In particular, SAR data collected by ERS-1/2, ENVISAT, ALOS-1, and COSMO-SkyMed platforms were independently processed to capture the long-term deformation behaviour of the volcano. To this aim the DInSAR technique known as Small Baseline Subset (SBAS) has been employed. SBAS is an effective and mature approach that allows us to detect the Earth surface deformation and to analyse its temporal evolution by generating mean LOS velocity maps and time series of LOS displacements. In particular, this technique relies on the use of multiple master multi-look interferograms generated via an appropriate selection of SAR data pairs characterized by small (less than a selected threshold) spatial and temporal baselines. The key objective of this data selection is to mitigate the noise (decorrelation) effects, thus maximizing the number of temporally coherent pixels (for definition of temporal coherence). The information conveyed by long-term time-series was also integrated with one associated to single interferograms, inferring the short-term behaviour of volcano across the paroxysm event occurred on December 28, 2014. To achieve this task, couples of SAR data acquired by the TerraSAR-X and Sentinel-1A platforms have been used. The preliminarily analysis of the obtained DInSAR-based results reveals a firm interaction between the structural surface deformation phenomena and the eruptive style of the entire volcanic edifice.

A contribute to the Italian Supersites volcanoes monitoring by using EO optical data

Malvina Silvestri

Istituto Nazionale di Geofisica e Vulcanologia, Centro Nazionale Terremoti, Roma, Italy

This work describes the INGV experience in the capability to import many different EO optical data into in house developed systems and to maintain a repository where the acquired data have been stored for generating selected products which are functional to face the different volcanic activity phases. Examples on the processing of long time series based EO data of Mt Etna activity and Phlegraean Fields observation by using remote sensing techniques and at different spatial resolution data (ASTER - 90mt, AVHRR -1km, MODIS-1km, MSG SEVIRI-3km) are also showed. Both volcanoes belong to Italian Supersites initiative of the geohazard scientific community. In the frame of the EC FP7 MED-SUV project (call FP7 ENV.2012.6.4-2), this work wants to describe the main activities concerning the generation of brightness temperature map from the satellite data acquired in real-time from INGV MEOS Multi-mission Antenna (for MODIS, Moderate Resolution Imaging Spectroradiometer and geostationary satellite data) and AVHRR-TERASCAN (for AVHRR, Advanced Very High Resolution Radiometer data). The advantage of direct download of EO data by means INGV antennas (with particular attention to AVHRR and MODIS) even though low spatial resolution offers the possibility of a systematic data processing having a daily updating of information for prompt response and hazard mitigation. At the same time it has been necessary the use of large archives to inventory and monitor dynamic and dangerous phenomena, like volcanic activity, globally.

MED-SUV e-infrastructure implementation for in-situ data: state of the art

Danilo Reitano[1], Giovanni Scarpato[2], Ida Aquino[2], Giovanna Berrino[2], Alessandro Bonforte[1], Tommaso Caltabiano[1], Antonio Caputo[2], Marcello D'Agostino[1], Andrea D'Alessandro[2], Luca D'Auria[2], Vincenzo D'Errico[2], Prospero De Martino[2], Mario Dolce[2], Francesco Guglielmino[1], Giuseppe Salerno[1], Salvatore Giammanco[1], Salvatore Mangiagli[1], Massimo Orazi[2], Emilio Pecora[1], Rosario Peluso[2], Salvatore Pinto[2], Michele Prestifilippo[1], Giuseppe Puglisi[1], Giuseppe Ricciardi[2], Ciro Ricco[2], Massimo Rossi[1], Fabio Sansivero[2], Claudio Serio[2], Letizia Spampinato[1], Salvatore Spampinato[1], Simona Scollo[1]

[1]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania - Osservatorio Etneo, Catania, Italy*
[2]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Napoli - Osservatorio Vesuviano, Napoli, Italy*

The main goal of Sub-task 3.2 of the MED-SUV Project is the design and the implementation of specific interfaces in order to transfer the in situ data into the integration and interoperability e-infrastructure. The data used by this Sub-task are intrinsically heterogeneous, and are acquired by different networks, partly due to the network different geographical location (Etna and Campi Flegrei Vesuvius). So the very first step for 3.2 e-infrastructure builders is to know the basic information about each dataset, the metadata creation process and also the discovery activity about data format and data access rules. A recognition and characterization process has been started for all the 19 different identified kinds of datasets. The datasets can be classified into four main groups: (1) in-situ geodetic data (i.e. GPS, tilt, levelling, etc.); (2) geochemical and thermal data (i.e. SO_2, CO_2 gas fluxes, thermal images); (3) Visible/IR images; (4) other in situ data (i.e. seismic real time/off line analysis). The e-Infrastructure foresees also data resulting from periodic campaigns and by particular activities (like the TOMO-ETNA experiment). According to Task 3.4, a brokering approach is the basis of the new e-Infrastructure. This approach will provide a uniform discovery and access to the data. For the implementation, metadata must be available and discoverable. Some datasets do not possess metadata in a standard format, however they are well known to the users and, in this phase, the 3.2 team worked side-by-side with the local data providers in order to make a survey of the available datasets. The aim of the survey was to collect all the available information about each dataset so as to define one or more standards, useful to produce the correct connection with Task 3.4. For this reason inside Task 3.2 a pilot experimental tool is in progress. This tool will allow i) designing new interfaces compliant with the brokering approach, and ii) making the MED-SUV data compliant with existing standards for future uses. In order to give the opportunity for the MED-SUV users to have an immediate data access, the majority of the data providers choose to make data (and metadata) available through the MED-SUV data repository. Currently, a new repository structure has been designed. It is realized using a redundant storage area, located between the sites of Catania (INGV - Osservatorio Etneo) and Naples (INGV- Osservatorio Vesuviano) with the goal to provide shared data to MED-SUV users.

SO_2 flux at Mount Etna between 2005 and the 2011: results and perspectives

Giuseppe G. Salerno[1], Tommaso Caltabiano[1], Michael R. Burton[2],
Vincenza Longo[1], Filippo Muré[1]

[1]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania - Osservatorio Etneo, Catania, Italy*
[2]*University of Manchester, School of Earth, Atmospheric and Environmental Sciences, United Kingdom*

Mount Etna is one of the most active volcanoes in the world and is in an almost constant state of activity. Accounting for ~15% of the global flux of volcanic S into the Earth's atmosphere, Etna is also regarded as one of the strongest volcanic sources of sulphur dioxide (SO_2) emissions to the atmosphere. SO_2 flux is systematically measured at Mount Etna since 1987 using COSPEC, by the FLAME scanning spectrometer network since 2004, and by a permanent SO_2 Camera since 2015. In the period between 2005 and 2011 Mount Etna displayed an intense eruptive activity, which spanned from soundless lava flows to vigorous lava fountains. We present here bulk SO_2 flux observations carried out in this timespan. Throughout the seven year noteworthy changes in gas flux were observed strongly correlated with the eruptive activity at both short and long-time scale. SO_2 flux varied widely describing waxing-waning steps which suggest cycles of volatile-rich magma supply from the depth to the shallow part of the feeder conduit. Considering the original content in sulphur of Etna's magma, the balance between the erupted magma and the SO_2-degassed magma budget was explored. Short- and long-time scale estimates of degassed magma-volume allowed us discriminating between steady-state magma degassing-erupted transfer processes and unbalances volumes due to excess degassing.

In situ data: the seismic records of Mt. Etna

Salvatore Spampinato, Salvatore Alparone, Marcello D'Agostino,
Giuseppe Di Grazia, Ferruccio Ferrari

Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania - Osservatorio Etneo, Catania, Italy

Three kinds of seismic data recorded in the Etna area during the time span 2005-2011 have been selected to be shared with MED-SUV users: i) raw continuous signals from permanent broad band digital stations; ii) an earthquake catalogue, concerning the hypocentre of local shocks calculated by expert personnel at Osservatorio Etneo (INGV-OE) by means of off-line analysis of digital seismograms; iii) the RMS amplitude value of the continuous background seismic signal. For preparing the first type of data, we considered the original seismic records of the INGV-OE seismic network. Due to these records are stored as compressed files from the original SUDS format, to achieve our objective several work phases are necessary: 1) copying data from the INGV-OE repository to an intermediate data storage; 2) decompression of data files; 3) extracting the records of selected seismic stations; 4) converting data from SUDS to SAC format; 5) moving the obtained SAC files into the MED-SUV repository. This chain of operations is large time consuming. Up to date, we converted, and shared, about two years of continuous raw data which correspond to about 1 TB. The earthquake catalogue reports parametric information (latitude, longitude, depth, magnitude, etc.) of the hypocentre of ca 800 earthquakes. This catalogue refers to shocks with magnitude greater than or equal to 2.0 and error threshold not greater than fixed values (e.g., horizontal and vertical hypocentral errors less than or equal to 2.0 km, RMS travel-time residual less than or equal to 0.35s, etc.). These data are shared in ASCII format. The RMS amplitude value of the continuous background seismic signal has been calculated by an automatic tool which processes the on-line signal from remote seismic stations. The amplitude data are calculated both in the whole unfiltered continuous signal, and in frequency bands 1 Hz wide, between 0.5 and 15 Hz. The format of data is ASCII. For treatment and characterization of each type of data, we also defined appropriate metadata. As regards the metadata related to the continuous raw data time series, any useful technical specifications, along with the geographical position of the seismic stations selected have been collected. For each station we reported this information in specific files coded in standard SEED format (SEED data less). Metadata of the earthquake catalogue are provided in a separate ASCII format file and they concern mainly the parametric information of the hypocentres.

3D displacement maps of the Mt. Etna December 2014 eruption by applying the SISTEM method to GPS and DInSAR data

Alessandro Bonforte, Francesco Guglielmino

Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania - Osservatorio Etneo, Catania, Italy

Thanks to the availability of geodetic in-situ data collected on Mt. Etna, it has been possible to validate and integrate the available SAR data with the GPS ground deformation data, applying the SISTEM approach. The SISTEM approach simultaneously integrates all the available geodetic datasets (i.e. GPS displacement vectors on sparse benchmarks and InSAR displacement maps), providing high-resolution 3D displacement maps by taking advantage of the positive features of each dataset, in this case the high temporal and spatial resolution of the COSMO-SkyMed and TERRASAR-X X-band SAR data, the good coherence of SENTINEL-1 C-band SAR data and the 3D displacement components provided by GPS with sub-cm accuracy level. We applied the SISTEM method for computing 3D high-resolution surface displacement maps of Mt. Etna related to July 2014 - January 2015 period, in order to investigate and detail the ground deformation associated with the 28 December 2015 eruption

The preliminary SISTEM results have depicted the displacement pattern, consistent with the effects produced by a very shallow sub-vertical dyke intruding just beneath the New South East Crater (NSEC), with a NE-SW trend, perfectly matching with the location of the vents and of the ground fractures observed in the field. The displacement pattern resulting by applying the SISTEM integration method provides an accurate spatial characterization of ground deformation, well constrained by the multiple SAR data and ground GPS measurements. The proposed technique will be applied on other volcanic areas, starting from those planned to be investigated in the framework of MED-SUV project.

The wet refractivity tomography for improving the DInSAR deformation measurements on Mount Etna

Massimo Aranzulla[1], Francesco Guglielmino[1], Giuseppe Puglisi[1], Claudia Spinetti[2]

[1]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania - Osservatorio Etneo, Catania, Italy*
[2]*Istituto Nazionale di Geofisica e Vulcanologia, Centro Nazionale Terremoti, Roma, Italy*

In the frame of the EC FP7 MED-SUV project (call FP7 ENV.2012.6.4-2), we carried out a study to improve the precision of the current ground deformation monitoring at Mt. Etna volcano. With this aims the synergy between GPS and SAR techniques has been explored in order to reduce the atmospheric artefacts. The DInSAR technique plays an important role in the world of the earth observation techniques used in geodesy to monitor the volcanic areas. Among various perturbations affecting interferograms, atmospheric artefacts are one of the most significant and probably the most difficult to identify and reduce. Due to the complex orography of Mt. Etna and quite variable weather conditions, also due to the vicinity of the Mediterranean Sea, the atmospheric heterogeneities become even more pronounced. For these reasons the estimation of Mount Etna atmospheric anomalies using GPS measurements have noticeable importance to calibrate the SAR interferograms and to establish the "effective" ground deformation of the volcanic edifice. Since 1988, the Istituto Nazionale di Geofisica Vulcanologia, Osservatorio Etneo (INGV-OE) monitors ground deformations at Mt. Etna. Nowadays, the network geometry consists of 42 permanent stations that provide a dense coverage of most areas of the volcano edifice. The GPS data processing has been carried out by using the GAMIT software, by adopting appropriate processing parameters. Software was developed for deriving the tropospheric tomography starting from the GAMIT output. The code was validated by using synthetic tests which assume different structure of atmospheric anomalies and with random noise about twice severe than the typical errors of the GPS. The results of the tests proved that the tomography software is able to reconstruct the simulated anomalies faithfully. The results of the tomography previously obtained showed clearly important features of the refractivity field of the studied days. In this work, the wet refractivity tomography was applied on experimental data from DInSAR Sentinel-1 IW and GPS measured carried out on Mount Etna during the August 2014. In order to reduce the known problem of the correction for the antenna pattern, the interferometric process was performed only on one burst of one subset of Sentinel-1 IW data. The interferometric results shown a minor effect probably due to the atmospheric artefacts, located on the summit area of Mt. Etna, and the integration with tomographic data allow us to accept or reject this hypothesis. Strategies to calibrate the interferograms from the results of the atmospheric tomography will be discussed.

Reconstruction of SO_2 emission height time-series and plume age using a combination of satellite imagery, volcanic tremor and back trajectory modelling at Mt. Etna

Federica Pardini[1], Michael R. Burton[2], Giuseppe Salerno[3], Luca Merucci[4], Stefano Corradini[4], Sara Barsotti[5], Mattia de' Michieli Vitturi[1], Giuseppe Di Grazia[3]

[1]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Pisa, Pisa, Italy*
[2]*University of Manchester, School of Earth, Atmospheric and Environmental Sciences, United Kingdom*
[3]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania - Osservatorio Etneo, Catania, Italy*
[4]*Istituto Nazionale di Geofisica e Vulcanologia, Centro Nazionale Terremoti, Roma, Italy*
[5]*Iceland Meteorological Office, Iceland*

While much work has focused on detection of volcanic gas emissions from space, relatively little progress has been made on examining volcanic processes using satellite measurements of volcanic plumes. In theory, much information can be derived regarding the temporal evolution of an eruption from a single image of an eruption plume. This information could be used to constrain models of magma chamber emptying, and comparison with InSAR measurements of sin-eruptive deflation. The over-arching goal of the work presented here therefore is SO_2 flux time-series reconstruction using satellite imagery of SO_2 in volcanic plumes. One of the major sources of uncertainty in the determination of SO_2 abundances from satellite imagery is the plume height, and so we have focused on the development of a robust procedure that allows us to make accurate reconstructions of plume height time series. Starting from satellite images of SO_2 emitted from Mt. Etna, Italy, we identified specific pixels where SO_2 was detected and utilized the HYSPLIT Lagrangian back-trajectory model in order to retrieve the emission height and time of the eruption column over the volcano. The results have been refined using a probabilistic approach that allows calculation of the most probable emission height range. Previous work has highlighted that volcanic tremor is strongly connected to eruption intensity, and therefore, potentially to plume height. We therefore examined the relationship between volcanic tremor measured on Etna with our derived plume height time series. We discovered a relatively good agreement between the time series, suggesting that the physical processes controlling both the distribution of SO_2 in the atmosphere and the intensity of volcanic tremor are strongly coupled, through the explosivity of the eruptive activity. The synthesis of volcanic tremor and derived plume heights is a novel new approach, and opens the possibility of more quantitative analysis of SO_2 amounts in satellite imagery, and deeper insights into the volcanological processes driving eruptive activity.

Volcanic ash concentration during the 12 August 2011 Etna eruption

Simona Scollo[1], Antonella Boselli[2], Mauro Coltelli[1], Giuseppe Leto[3], Gianluca Pisani[4], Michele Prestifilippo[1], Nicola Spinelli[4], Xuan Wang[5]

[1]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania - Osservatorio Etneo, Catania, Italy*
[2]*CNISM and IMAA-CNR, Potenza, Italy*
[3]*Istituto Nazionale di Astrofisica - Osservatorio Astrofisico di Catania, Catania, Italy*
[4]*CNISM and Dipartimento di Fisica, Università di Napoli "Federico II", Naples, Italy*
[5]*CNISM and CNR-SPIN, Dipartimento di Scienze Fisiche, Università di Napoli "Federico II", Naples, Italy*

Etna is one of the most active volcanoes in the world with a recent activity characterized by powerful lava fountains that produce high eruption columns and disperse volcanic ash in the atmosphere. In this work we study the volcanic ash dispersal of the 12 August 2011 lava fountain event. During this activity, an eruption column rose up to several kilometres above sea level, and the volcanic plume was dispersed to the southeast. We used data from the visible camera of the Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Etneo and from a Lidar system. The visible camera installed in Catania, 27 km from the vent, was calibrated and able to evaluate the column height. The Lidar, installed at the "M.G. Fracastoro" astrophysical observatory of the Istituto Nazionale di Astrofisica in Catania, located 7 km from the Etna summit craters, measured backscattering and depolarization values of volcanic plume. From the video-surveillance system, we were able to estimate variations in the column height (peak value of 9.5 ± 0.5 km above sea level) with time. We derived the time-varying discharge rate (peak value of 60 m^3 s^{-1}) and determined the ash concentration using a volcanic ash dispersal model. The modelled ash concentration was compared with those obtained by Lidar using different particle effective radius, and differences are within the error bars. Volcanic ash concentrations range from 0.5 to 35.5 × 10^{-3} g m^{-3}. The comparison highlights that to improve volcanic ash forecasting during volcanic crises it is necessary to take into account the time-varying discharge rate of explosive eruptions.

Synergistic use of Lagrangian dispersion modelling, satellite- and ground-based measurements for the investigation of volcanic plumes: the Mount Etna

Pasquale Sellitto[1], Alcide di Sarra[2], Stefano Corradini[3], Marie Boichu[1,4], Hervé Herbin[4], Philippe Dubuisson[4], Geneviève Sèze[1], Daniela Meloni[2], Francesco Monteleone[5], Luca Merucci[3], Justin Rusalem[4], Giuseppe Salerno[6], Pierre Briole[7], Bernard Legras[1]

[1]*LMD-ENS, CNRS, Paris, France*
[2]*ENEA, UTMEA-TER, Rome, Italy*
[3]*Istituto Nazionale di Geofisica e Vulcanologia, Centro Nazionale Terremoti, Roma, Italy*
[4]*LOA, CNRS, Lille, France*
[5]*ENEA, UTMEA-TER, Palermo, Italy*
[6]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania - Osservatorio Etneo, Catania, Italy*
[7]*Laboratoire de Géologie-ENS, CNRS, Paris, France*

In this poster we show how the combined use of SO_2/ash plume dispersion modelling and remote observations from satellite and the ground can be used to study the influence of moderate volcanic activity on the optical and microphysical characterization of tropospheric aerosols at the regional scale. We analyse the Mount Etna lava fountain and gas/ash emission episode of 25-27/10/2013. This study is based on aerosol and SO_2 measurements made at the ENEA Station for Climate Observations (35.52°N, 12.63°E, 50 m asl) on Lampedusa island, on satellite observations, and on a Lagrangian model analysis. The used satellite dataset includes MODIS (MODerate resolution Imaging Spectroradiometer) true colour images, volcanic SO_2/ash retrievals and flux estimations, and SEVIRI (Spinning Enhanced Visible and InfraRed Imager) cloud top pressure estimations. Trajectory analyses are made with the FLEXPART (FLEXible PARTicle dispersion model) Lagrangian dispersion model. The combination of MODIS and SEVIRI observations, FLEXPART simulations, and ground-based observations at Lampedusa indicate that SO_2 and ash, despite the initial injection at about 7.0 km altitude, could have reached up to 10.0-12.0 km altitude, and influenced the aerosols size distribution downwind at more than 350 km distance, in the Southern sector of the Central Mediterranean. This study indicates that even a relatively small volcanic eruption can have an observable effect on the aerosol properties at the regional scale. The likely impact of the secondary sulphate aerosols on the aerosol size distribution at Lampedusa is also discussed.

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WP4

Talks

Laboratory experiments and fluid monitoring at Campi Flegrei to understand pressure transients in hydrothermal systems

Heiko Woith[1], Annarita Mangiacapra[2], Giovanni Chiodini[3], Thomas Walter[1]

[1]*GFZ German Research Centre for Geosciences, Potsdam, Germany*
[2]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Napoli - Osservatorio Vesuviano, Naples, Italy*
[3]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Bologna - Bologna, Italy*

The hydrothermal system beneath Campi Flegrei is strongly affected by sub-surface processes as manifested by the existence of a geothermal "plume" below Solfatara, associated with formation of mud-pools (Fangaia), fumaroles (Bocca Grande, Pisciarelli), and thermal springs (Agnano). Within the frame of MED-SUV (The MED-SUV project has received funding from the European Union Seventh Framework Programme (FP7) under Grant agreement no 308665), pressure transients in the hydrothermal system of Campi Flegrei shall be studied using a combination of laboratory experiments and continuous pressure/temperature monitoring at fumaroles, mud pools, hot springs, and geothermal wells. In total 8 monitoring sites were established to monitor pressure transients across the hydrothermal plume below Solfatara. Temporal variations of water temperature and water level are monitored along an EW-profile from Agnano to Fangaia. Autonomous devices are being used to record the water level and water temperature at 10 minute intervals.

Records reveal significant changes of the hydrothermal system in September 2013: significant water level and temperature drops were observed at the main spring of Agnano Termal. Such a phenomenon never occurred in the past decades, but in 2013 it had been observed several times according to technicians of the spa facility. Similar water level drops then repeatedly occurred in the following months. Continuous fluid measurements at a mud pool inside Solfatara called Fangaia revealed that (i) the chosen monitoring device (ceraDIVER) is appropriate to withstand the aggressive fluid (pH<1, CO_2, H_2S) for a reasonable time, and (ii) that water level and water temperature are dominantly controlled by rain water during the observation period from October 2013 until November 2014. At first glance, fluid monitoring at a well providing hot water (82 °C) for the Pisciarelli tennis club seems to be fully useless to access natural changes in the Campi Flegrei fluid system. The signals clearly depict the pumping schedule of the facility. At a second thought, the data provide a unique opportunity to monitor potential permeability changes in the aquifer directly since the time series is a sequence of discrete well pumping tests - opposed to the indirect approaches applied by others who deduced earthquake-related permeability changes from Earth tide variations.

Gas bubbles are likely to play a major role with respect to spatio-temporal variations in shallow fluid systems below Solfatara. Thus, additional to the field measurements we investigate potential bubble-related mechanisms capable to increase fluid pressure. The BubbleLab at GFZ has been setup. We are able to simulate earthquake ground motions with a shaking table, track the size and velocity of rising bubbles via a camera system, and quantify transients with a set of pressure sensors (up to 400 Hz). Furthermore, an ultrasound transmitter–receiver-system (Geotron USG40 with UPG 250/UPE 250 kHz) allows detecting bubbles in sediments. We designed an experimental setup to simulate dynamic triggering effects with and without particles under varying frequency and amplitude conditions. Results suggest that a trigger external to the actual vents, either sub-surface or remote (e.g. earthquake) might be capable of triggering the hydrothermal system.

Seismicity and ground deformation signals at Campi Flegrei from dilatometer and long-baseline tiltmeter data

Roberto Scarpa[1,2], Bellina Di Lieto[3]

[1]*Dipartimento di Fisica, Università di Salerno, Salerno, Italy*
[2]*AMRA Scarl, Napoli, Italy*
[3]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Napoli - Osservatorio Vesuviano, Napoli, Italy*

Since spring 2004 a research project has been developed in Italy to install borehole Sacks-Evertson strainmeters aimed to improve monitoring systems of the Italian volcanoes. 6 borehole dilatometers have been installed around Campi Flegrei and Vesuvius during 2004-2005. This small network has been implemented by two arrays of long-baseline water tube tiltmeters installed in underground tunnels since 2008. Relevant strainmeter and tiltmeter data have been collected and analysed at the instruments installed at Campi Flegrei during the recent unrest episodes. Renewed activity started since 2004-2005, characterized by a quite low rate of vertical displacement, amounting initially to a few cm/year. A long term strain episode occurred during summer 2006, in correspondence to an increase of CO2 emission and displacements measured also by tiltmeters and GPS transducers. This strain episode preceded the seismic activity by few months, as also observed during the 1982 most significant unrest. Other aseismic slip episodes have been recorded in 2009, in correspondence of the renewal of gas emission activity at Solfatara, in 2010, one day before a seismic swarm, and in September 2012, few days before the most significant seismic swarm occurred after the 1982-1984 uplift. The time scale of these phenomena is ranging from some hours to several days, putting further constraints on the origin of ground uplifts at Campi Flegrei. In March 2010 borehole-strainmeters and Michelson tiltmeters registered an abrupt 40 minute change in strain associated with a swarm of microseismicity on two normal faults near the instruments. Deformation models of the event show that the strain changes can be attributed to volume decreases in a previously-identified subsurface magma chamber with ellipsoidal geometry, but that the strain changes resulting from faulting were too small to be detected. The association of normal faulting with transient subsurface magma chamber deflation may account for the ubiquitous normal faulting that is recorded in the Campi Flegrei region. The inferred transient decrease in magma volume occurred at a rate that was more than two orders of magnitude slower than typical magma volume increase rates associated with inflation in the region, suggesting that microseismicity depends significantly on strain rate changes. The 20 minute delay between the onset of strain and the occurrence of microseismicity may have utility in forecasting future damaging events, however, due to the unavailability of simultaneous strain and tilt data for other seismic swarms, we are unable to conclude that the sequence of events is ubiquitous or an unique occurrence.

Imaging the emplacement of a magmatic sill beneath Campi Flegrei in 2012-2013

Luca D'Auria[1], Susi Pepe[2], Raffaele Castaldo[2], Flora Giudicepietro[1], Giovanni Macedonio[1], Patrizia Ricciolino[1], Pietro Tizzani[2,1], Francesco Casu[2], Riccardo Lanari[2], Maria R. Manzo[2], Marcello Martini[1], Eugenio Sansosti[2], Ivana Zinno[2]

[1]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Napoli - Osservatorio Vesuviano, Napoli, Italy*
[2]*Centro Nazionale delle Ricerche - Istituto per il Rilevamento Elettromagnetico dell'Ambiente, Napoli, Italy*

Campi Flegrei caldera (Southern Italy) is among the areas with the highest volcanic risk in the world due to about 1 million people living within and around the caldera borders. In recent years Campi Flegrei caldera has experienced an accelerating uplift rate of the ground deformation. In particular, during the April 2012 - January 2013 time interval the caldera has shown a rapid uplift of about 11 cm with a peak rate of about 3 cm/month. This event led the Italian Civil Protection to raise the alert level from green to yellow. In this scenario, we applied a joint inversion technique to DInSAR and GPS measurements, recorded between 2012 and 2013 at Campi Flegrei caldera, to image the kinematics of the emplacement of a magmatic sill beneath the caldera. In particular, we exploited the displacement time series that we obtained by processing 90 SAR images acquired from the COSMO-SkyMed sensor constellation along ascending orbits via the well-known DInSAR algorithm referred to as SBAS algorithm, and the displacement measurements provided by 14 continuous GPS stations deployed within the caldera and belonging to the permanent INGV-OV monitoring network. We applied a geodetic imaging technique to determine the spatial and temporal evolution of the ground deformation source in the selected period. The preliminary results show that the most likely source has a planar geometry and is located at a depth of about 3100 m; this is in good agreement with earlier studies relevant to previous intervals proposing that the ground deformation source at Campi Flegrei consists in an inflating sill. The retrieved temporal pattern of the source geometry reflects that of a growing sill that, at the end of the considered period, has a roughly elliptical geometry with an extension of about 5 km in the NW-SE direction and about 4.5 km in the NE-SW one. The maximum aperture of the sill is of about 35 cm at its centre. To understand the dynamics of this phenomenon we used a numerical model of the emplacement of a magmatic sill, to fit the retrieved geometry. The parameters to be determined are: the average magma viscosity, the amount of magma already present in the sill before the 2012-2013 episode and the magma injection rate. The injection rate has two main peaks on September and December 2012, and a smaller one on March 2013. The first two peaks have a value of about 0.25 m^3/s and duration of 3-4 months. The total amount of injected magma is of about 0.004 km^3. The results also show that the most likely value for the viscosity is between 10^4-10^5 Pa·s. This value agrees with the viscosity postulated for the most common magmas erupted at Campi Flegrei in the last millennia. Using a FE modelling, we also found a causal relationship between the sill emplacement and the occurrence of a seismic swarm on Sep. 2012. On these premises we postulate that the emplacement of sills is a common mechanism in the dynamics of Campi Flegrei but probably also in other unresting calderas.

2D MT resistivity modelling of the Solfatara-Pisciarelli-Agnano geothermal area

Agata Siniscalchi[1,2], Simona Tripaldi[1,2], Gerardo Romano[1], Luca D'Auria[3], Zaccaria Petrillo[3]

[1]*Dipartimento di Scienze della Terra e Geoambientali, Università degli Studi di Bari ALDO MORO, Bari, Italy*
[2]*AMRA S.c.a r.l., Napoli, Italy*
[3]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Napoli - Osservatorio Vesuviano, Napoli, Italy*

An audiomagnetotelluric-magnetotelluric survey in the period band 0.00001-8 s was performed during 2014 in the eastern border of the Campi Flegrei inner caldera. Twenty-two soundings, among a total of forty-three, were selected on a WSW-ENE profile that crosses the main volcanological surface evidences (Solfatara, Pisciarelli and Agnano). The profile trace orientation is almost consistent with main geoelectrical strike direction estimated by tensor analysis (N60°E). Impedance decomposition and rotation into the estimated strike angle was applied to each sounding before running the 2D inversion. The resulting model images the resistivity distribution up to 3 km of depths and provides considerable information about the geothermal system acting in the area.

The audiomagnetotelluric (AMT) survey performed in the framework of MED-SUV project consists of 43 soundings. A Stratagem EH4 system was used. In order to record data in the frequency range 0.1-100000 Hz two distinct sets of sensors were adopted. Furthermore, to improve signal-to-noise ratio, a controlled source in the frequency range from 1000 Hz to 64000 Hz was used during the acquisition if data quality was low in such frequency range. The source is an unpolarized transmitter consisting of two horizontal magnetic dipoles and was located far enough away to fulfil the plane wave hypothesis, but close enough to see the transmitter signal. Estimates related to the surveys carried out within the Solfatara area are of very good quality, while those relative to surveys conducted along the Pisciarelli-Agnano axis are the most affected by anthropogenic noise. To obtain less noisy and more reliable data, the final apparent resistivity and phase curves were cleaned up from outliers. Data analysis was carried out frequency by frequency for each sounding. Weaver's criteria on rotational invariants (WAL) were applied for the study of the dimensionality of electrical structures in the subsurface. This analysis is particularly important to determine the best approach for the purposes of the inversion of a given dataset (1D, 2D, 3D). It also allows determining the presence of galvanic distortions and provides information such as the variations of the geoelectric strike as a function of the investigated depth. The WAL analysis results indicate a predominant strike direction of N60°E and prevailing 3D effects in the lowest frequency decade. The data set was hence undistorted and rotated into the strike direction in order to perform a 2D inversion. In the annexed figure the model obtained from simultaneous inversion of the TM and TE apparent resistivities and phases is shown. The variable that controls the amount of regularization (tau, smoothing) was set to 5 and a uniform 30 Ohm.m half-space was used as starting model. Weight on fit was set mainly on phase (phase values are not affected by static shifts) by assigning larger error floors to the apparent resistivity than the phases: 5% for phases and 10% for resistivity. After 60 iterations the rms was 1.9.

Resistivity values, which image the first 3 km of depths along the present profile, range from 1 (or slightly less) to 300 Ohm.m. Very high conductive zones are recovered in the shallower 500 m in correspondence of Solfatara, Pisciarelli and Agnano, but this last appears separated by the formers by a structural high resistive border. On the western side of the profile, just in correspondence of the Fangaia mud pool, resistivity assume value as low as 1 Ohm.m. In the surrounding zones (Solfatara and Pisciarelli area), these very low resistivity values are reached deeper. As reported by widespread international literature, the recovered resistivity signature well matches with the behaviour of geothermal systems in its shallower part, where temperature

ranges between 70 and 200°C. The cause of this has been linked with the type of clay alteration that occurs in this temperature range as a consequence of hydrothermal fluids circulation. In the Solfatara-Pisciarelli area, the conductive zone assumes even the shape of a cap rock overlaying a resistive reservoir (propylitic zone) in which temperature exceeds 200°C. The clay alteration layer is expected to have a very low permeability, but some gaps in this layer appear just in correspondence of the surface manifestations of gases. We further note that above Pisciarelli a tinning of the clay layer appears. In order to appreciate the seismicity distribution in the studied area, we selected the events located in a 1 km wide band centred on the profile and we projected them onto the resistivity image. The selected earthquakes belong to the last decade (2005-2015). As one can appreciate, the seismicity is mainly located in the eastern side of the resistive core above Pisciarelli. Finally, in the central part of the profile, the resistivity distribution images the eastern side of the Agnano crater inside which the resistivity assumes very low values too.

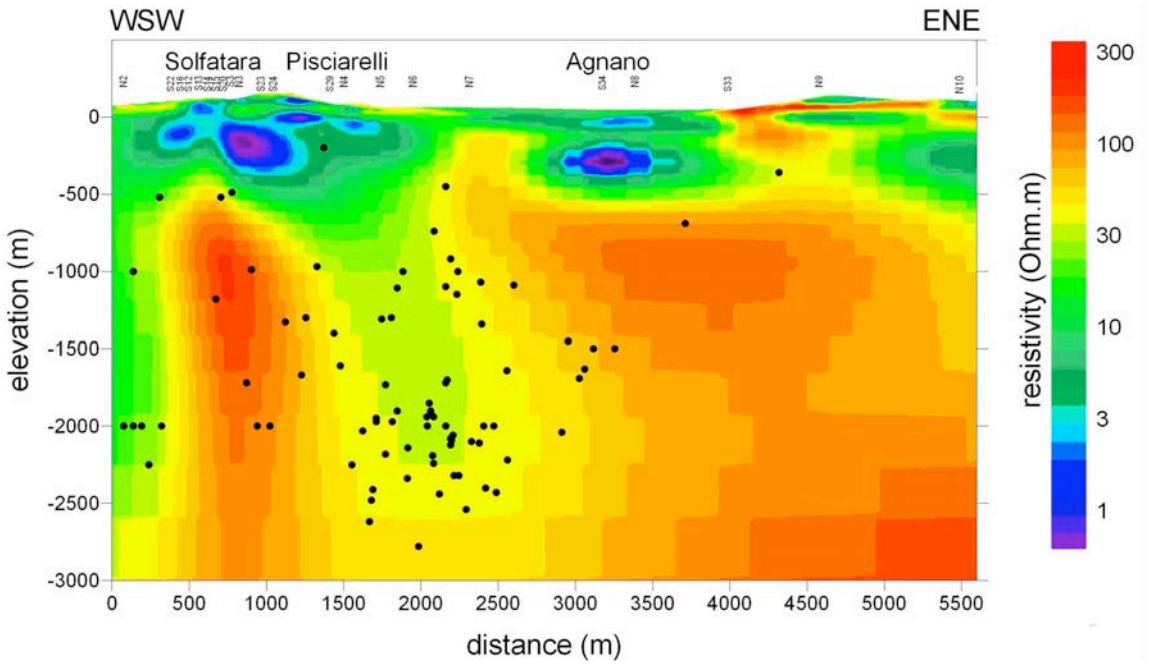

Figure 1. 2D resistivity model of the AMT-MT profile crossing the Solfatara-Pisciarelli-Agnano area. Dots represent the seismic events located in a 1 km wide band centred on the MT profile and belonging to the period 2005-2015.

DC resistivity models at Solfatara and Vesuvius. Insights into their shallow hydrothermal systems

Jean Vandemeulebrouck[1], Anthony Finizola[2], Marceau Gresse[1], Svetlana Byrdina[1], Annarita Mangiacapra[3]

[1]*Institut des Sciences de la Terre, Université de Savoie, IRD, France*
[2]*Institut de Physique du Globe de Paris, Laboratoire GéoSciences Réunion, Université de la Réunion, Paris, France*
[3]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Napoli - Osservatorio Vesuviano, Napoli, Italy*

Campi Flegrei: In order to build a 3-D model of the electrical resistivity at the Solfatara Crater, we performed several new 1-km-long DC resistivity tomography to constrain the large scale 3-D model, and several dense surveys in the fumarolic and Fangaia area. We also performed a complete mapping of CO_2 flux, self-potential and surface temperature in the Crater. Our aim is to gain insights into the structure of the shallow hydrothermal system. We present a large-scale model of the Crater system, a model of the liquid-saturated plume in the Fangaia area, and a model of the gas-saturated plume and overlying condensate layers below the fumarolic area. We also present the results of a time-lapse experiment of electrical resistivity monitoring at Solfatara that shows the occurrence of gas pulses into the system mid-2014.

Vesuvius: One profile coupling DC electrical resistivity tomography (Wenner configuration), self-potential, soil CO_2 degassing and sub-surface (30 cm depth) temperature have been performed, crossing the entire edifice of Somma-Vesuvius, along a NW-SE direction. Our profile cross 3 important structural boundaries: (1) The Somma caldera, (2) the 1631's caldera and (3) the 1906's crater.

For SP measurements, the comparison of our NW-SE profile with the SP data collected in 2001-2003 allow defining a very good correlation between the high SP gradient area with the 1906's crater boundary. This result clearly shows the importance of 1906's crater boundary in constraining the lateral extension of what can be called "the upper hydrothermal system extension" of Vesuvius. On both sides of the volcano, going down, several hundreds of meters are necessary to achieve the lateral extension of the hydrothermal system of Vesuvius. This second boundary can be called the lower hydrothermal system extension, and can be seen both on SP and ERT profile. It is interesting to note that at depth, no crater boundary is responsible for limiting the lateral extension of the hydrothermal system, as it is often the case on other volcanoes (e.g. Stromboli with the NeoStromboli crater boundary [Finizola et al., 2006] or Vulcano with the Gran Cratere boundary [Revil et al., 2008].

This survey allows locating the hydrothermal extension of Vesuvius, up to 450-500m depth. Several structural boundaries were evidenced as acting as preferential drains for CO_2 release, like 1631's caldera, 1906's crater and 1944's crater boundaries. The rise of the conductive body on the NW flank is located close to the eccentric cone of Colle Umberto, and Colle Umberto lava flow. Therefore a relation could be hypothesized with this geological object. Due to the sharp and near vertical transition on the NW side of this conductive body, it can be hypothesized that this latter could be related with a fault coupled with a local and old hydrothermal system related with the thermal energy of the Colle Umberto eccentric cone.

RICEN: Repeated InduCed Earthquakes and Noise @Solfatara, Campi Flegrei

Gaetano Festa[1,2], Marco Serra, Ortensia Amoroso[1], Pier P. Bruno[3], Marco Pilz[4], Philippe Roux[5], Guido Russo[1], Heiko Woith[4], Aldo Zollo[1,2]

[1]AMRA Scarl, Napoli, Italy
[2]Università degli Studi di Napoli Federico II, Napoli, Italy
[3]The Petroleum Institute, Abu Dhabi, United Arab Emirates
[4]GFZ German Research Centre for Geosciences, Potsdam, Germany
[5]ISTerre, Université de Savoie, IRD, CNRS, Campus Scientifique, Le Bourget du Lac F73376, France

RICEN is a series of experiments whose goal is to study the changes in the elastic properties of the medium at small scales through repeated observations over time. RICEN is mostly oriented to the use of seismic waves (both in passive and active modes) as a diagnostic tool. Nevertheless, auxiliary experiments were conducted at the same time, such as resistivity, seismo-electric and magneto-telluric measurements. The main goal of RICEN is studying the structural changes of a volcanic structure, through the recognition of changes in seismic records acquired at a dense seismic network. The investigation area is the Solfatara, a volcano in the Campi Flegrei caldera, characterized by an intense hydrothermal shallow activity. The initial phase (Pilot Phase) of RICEN was held from 23 to 26 September 2013. The goal of the pilot phase was to study the feasibility of a repeated experiment, and the resolution of the resulting velocity model. The ambient noise was acquired at 54 GFZ three components geophones, sparsely distributed inside the crater for a total duration of the records of about 16 hours. For the active part about 100 shots by MiniVIB were recorded at 240 seismic stations, placed on a regular grid of 115 m x 90 m^2 area in front of the Fangaia. An additional array was located within the area of the Fangaia (24 geophones, 3 components from GFZ), with a spiral configuration. The second experiment RICEN FIRST ACT was realized from May, 19 to 23 May, 2014. The ambient noise and the active phase of the experiment in the 3D grid were acquired with the same source-station geometry of the RICEN - PILOT phase. Moreover about 400 m long 1D profile was performed with 215 sensors located at 2 m distance along the profile and 116 shots about every 4 m. At the same time of the Vibroseis energizations, seismo-electric, magneto-telluric, CO_2 and temperature measurements were performed in the area, to possibly recognize seismic signatures of the Vibroseis. The third and final phase of the experiment RICEN SECOND ACT was realized from 10 to 14 November, 2014. After collection of ambient noise and active data on the grid, a 400 m long 1D profile, which crossed the whole area of the Solfatara in the NW - SE direction, orthogonally to the first one, was performed with 240 sensors located at 2m distance along the profile and 75 shots about every 4 m. Data are available online to the project participants at the ftp site ftp://isnet.fisica.unina.it/, where all files from different seismic experiments are uploaded both for active and passive seismic in different folders. They are available in original format or in SAC format before and after a manipulation aimed to improve the data quality. Until today, data from the RICEN - PILOT phase and from the 2 lines array of the first and second phase have been processed and analysed. For the pilot phase data recorded at all stations of the grid, we obtained 3D P and S wave tomographic models of the subsoil covered by the grid. P model was obtained from linearized inversion of P wave first arrivals, manually picked on cross-correlated minimum phase traces. The S model was obtained through the inversion of the phase and group velocities dispersion curves, measured on 96 overlapping sub-grids and for each of them assuming a 1D propagation medium. Dispersion curves were also available from ambient noise analysis. Also a 2D long profile was analysed to retrieve a tomographic 2D model of the area and the section migrated at depth to retrieve the bottom of the crater in the area.

Signals from poroelastic fluid flow in volcanic environments

Karen Strehlow[1], Armando Coco[1], Joe Gottsmann[1], Fiona Whitaker[1], Alison Rust[1], Gilda Currenti[2], Alia Jasim[1], Sarah Bunney[1]

[1]*School of Earth Sciences, University of Bristol, Bristol, United Kingdom*
[2]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania - Osservatorio Etneo, Catania, Italy*

We present results from two investigations into poroelastic flow in volcanic environments stemming from strain changes in confined aquifers and hydrothermal fluid circulation from magmatic unrest. In the first study we use Finite Element Analysis to simulate the response of confined aquifers with markedly different Young's Moduli to volumetric strain induced by pressurised magma reservoirs. The time-dependent, fully coupled models simulate crustal deformation accompanying chamber pressurisation and the resulting hydraulic head changes as well as porous flow in the aquifer. The simulated deformational strain leads to cm (compliant aquifer) to meters (stiff aquifer) of hydraulic head changes; both strain and hydraulic head change with time due to substantial porous flow in the hydrological system. Results indicate that piezometric head changes are particularly sensitive to chamber volume and shape, followed by chamber depth and the phase of the pore fluid. The Young's Modulus and permeability of the aquifer, as well as the strength of pressurisation also have significant influence on the hydraulic head signal. While source characteristics, the distance between chamber and aquifer and the elastic stratigraphy determine the strain field and its partitioning, flow and coupling parameters define how the aquifer responds to this strain and how signals change with time. Piezometric head changes mirror volumetric strain and water wells can therefore serve as comparatively cheap strain meters that could provide important insights into pre-eruptive dynamics. The second study focuses on the quantification of ground deformation and gravity changes caused by an anomalous rate of injection of magmatic fluids into a shallow-seated hydrothermal system. The models take account of lithological heterogeneities as well as fault systems observed at the Campi Flegrei caldera. Key findings include that the pore pressure evolution dictates ground deformation at the beginning of unrest, but is overtaken by the deformation induced by thermal effects after about 20 to 40 years. After a transient positive increase over the first year of unrest, gravity changes become negative and decrease monotonically towards a steady state value with time. The amplitude of the gravity changes is more pronounced for higher injection rates. The behaviour is, however, highly nonlinear with time. The time needed to change sign (from positive to negative) appears to be independent of injection rates. While simulations can resolve the temporal evolution of signals observed at the Campi Flegrei since 1982, their smaller observed amplitudes may point towards an involvement of a deeper magmatic source in the recent unrest.

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WP4

Posters

Periodic surveys with a Multigas-type station

Annarita Mangiacapra[1], Paolo Capuano[2,3], Giovanni Chiodini[4]

[1]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Napoli - Osservatorio Vesuviano, Napoli, Italy*
[2]*Università degli Studi di Salerno, Salerno, Italy*
[3]*AMRA, Napoli, Italy*
[4]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Bologna, Bologna, Italy*

The Solfatara crater, together with the surrounding areas of Pisciarelli and Agnano, is considered the most active volcanic sector of the Campi Flegrei caldera, recently affected by clear signs of potential reawakening. Intense, diffuse degassing and fumarolic activity affect Solfatara, where, a systematic monitoring of the chemical-isotopic compositions of the main fumaroles started since the early 80s and led to the definition of the conceptual geochemical reference model of the hydrothermal system [Caliro et al., 2007]. With the primary aim of determining the fluxes and analysed the gas species from the main plums that characterize this very active and dangerous volcanic area, we have performed several acquisition campaigns in Solfatara volcano and in Pisciarelli sites by a portable Multigas-type station (MultiGAS). The device was developed at the Istituto Nazionale di Geofisica e Vulcanologia Sezione di Palermo and is a multi- component gas analyser system able to measure the concentrations of major volcanic gas species: CO_2, SO_2, H_2S, H_2, H_2O. The method, detailed described in Aiuppa et al. [2013], consists on a sequences of transects across a section of the analysed plume, orthogonal to the plume transport direction. During each measurement, the plume gas is steadily pumped into the sensor's box and a data-logger board captures the output signals from the sensors at a rate of 0.5 Hz. During the measurements, a video camera pointing toward the vents acquires image sequences of the atmospheric plume at 25-100 frames/s. These sequences are then processed to calculate the plume transport speed. From December 2014, we have performed more than 20 traverses at Solfatara and Pisciarelli sites and acquired gas concentration data, then processed using custom made software (Ratiocalc), which automatically runs the retrieval methodology. From the processed data we have derived gas concentration maps. Afterward, integrating the estimated concentration over a cross section of the analysed plume (perpendicular to the plume transport direction) and multiplying by the plume transport mean speed; we can also determine the flux of the analysed gas species from the main fumarolic vents. In addition, new δ34S isotopic measurements have been carried out on n. 21 selected samples collected from the Bocca Grande fumarole in the Solfatara crater, during the 2008- 2014 period. All samples have been prepared through oxidation and acidification and have been analysed at the NERC Isotope Geosciences Laboratory, British Geological Survey. New δ34S data range between +0.8‰ and +0.1‰ with a mean value of +0.33‰ and a standard deviation <0.2‰. When comparing our data with the previous analysed one, we notice an increase of the new δ34S values respect to the data related to the period 1983-1987 and a decrease respect to the 1998-2001 data. These isotopic variations are under study and will be used to investigate possible sulphur source changes during the last unrest period at Campi Flegrei caldera.

4-D monitoring of the Solfatara crater (Italy) by ambient noise tomography

Marco Pilz[1], Stefano Parolai[1], Gaetano Festa[2], Heiko Woith[1]

[1]*GFZ German Research Centre for Geosciences, Potsdam, Germany*
[2]*Università degli Studi di Napoli Federico II, Napoli, Italy*

Imaging shallow subsurface structures and monitoring related temporal variations are two of the main tasks for modern seismology. Although many observations have reported temporal velocity changes, e.g., in volcanic areas and on landslides, new methods based on passive sources like ambient seismic noise can provide accurate spatially and temporally resolved information on the velocity structure and on velocity changes. The success of these passive applications is explained by the fact that these methods are based on surface waves which are always present in the ambient seismic noise wave field because they are excited preferentially by superficial sources. Such surface waves can easily be extracted because they dominate the Green´s function between receivers located at the surface. For real-time monitoring of the shallow velocity structure of the Solfatara crater, one the forty volcanoes in the Campi Flegrei area characterized by an intense hydrothermal activity due to the interaction of deep convection and meteoric water, we have installed a dense network of 50 seismological sensing units covering the whole surface area in the framework of the European project MED-SUV. Continuous recordings of the ambient seismic noise over several days as well as signals of an active vibroseis source have been used. Based on a weighted inversion procedure for 3D-passive imaging using ambient noise cross-correlations of both Rayleigh and Love waves, we will present a high-resolution velocity model of the structure beneath the Solfatara crater. We discuss why and how it is possible to perform high precision and real-time monitoring of temporal changes in the properties of the propagation medium at small scales. In particular, we will focus on the depth resolution of the presented approach and further discuss the perspectives of noise-based real-time 4-D tomography.

Coarse grained parameters for detection of volcano-tectonic activity inferred by CICA

Paolo Capuano[1,2], Enza De Lauro[2,3], Salvatore De Martino[3], Mariarosaria Falanga[3], Simona Petrosino[4]

[1]*Dipartimento di Fisica "E.R. Caianiello", Università di Salerno, Fisciano (SA), Italy*
[2]*AMRA Scarl, Napoli, Italy*
[3]*Dipartimento DIIEM, Università di Salerno, Fisciano (SA), Italy*
[4]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Napoli - Osservatorio Vesuviano, Napoli, Italy*

The main aim of this work is to recognize the occurrence of seismic VT activity and its discrimination among other active and persistent natural and/or artificial sources, such as meteo-marine and anthropogenic noise. This task is of interest because it would support the routine practices of the observatories, considering that on the hourly scale events of very small energy are often completely hidden and not even the tedious work of operators can be resolved. To achieve that goal we adopt a robust automatic method, namely the Convolutive Independent Component Analysis (CICA), which in involves higher-order statistics in frequency domain. This technique is successful in seismological framework in the case of seismic signals, which can be considered as the convolution of time delayed source signals. In this work, we focus on Volcano Tectonic (VT) activity at Campi Flegrei Caldera (Italy) during the 2006 ground uplift. The activity is characterized approximately by 300 low-magnitude (Md < 2; for the definition of duration magnitude, see Petrosino et al., [2008]) VT earthquakes. Most of them were concentrated in distinct seismic sequences with hypocentres mainly clustered beneath the Solfatara-Accademia area, at depths ranging between 1 and 4 km b.s.l.. CICA is fruitfully applied to massive data on hourly scale obtaining a separation among different independent sources. Specifically, the identification of meteo-marine (< 1 Hz), anthropogenic noise (mainly affecting [8-14] Hz frequency range), and hydrothermal tremor (at about 0.8 Hz) is achieved in absence of VT activity, defining the background level. Variations of that underlying condition appear in approaching to the period of intense low-energy VT activity. Namely, a further component in 13-15 Hz compatible with the typical corner frequency of VTs is extracted. We propose a coarse-grained procedure directly applied to massive data separated through CICA, which would provide fast alert on the occurrence of even very-small VTs representing a suitable "observable" to monitor in the observatory practice.

RICEN seismoelectromagnetic experiment

Agata Siniscalchi[1,2], Gerardo Romano[1], Marianna Balasco[3], Simona Tripaldi[1,2], Sabatino Piscitelli[3], Enzo Rizzo[3]

[1]*Dipartimento di Scienze della Terra e Geoambientali, Università degli Studi di Bari ALDO MORO, Bari, Italy*
[2]*AMRA S.c.a r.l., Napoli, Italy*
[3]*Istituto di Metodologie per l'Analisi Ambientale, CNR, Potenza, Italy*

We present the first results of electromagnetic (EM) signals recorded during RICEN experiment on May, 20-21, 2014. In order to explore the seismo-electromagnetic coupling in porous media, three magnetotelluric stations (electrical and magnetic variable field) were installed at different sides of the 3D central grid of the active seismic experiment. Careful data analysis clearly shows that measurable signals are associated to each shot in the magnetic field components. The effects on the electrical field components are more difficult to detect, due to the strong amplitude of the power line signals affecting the same frequency range of the seismic sources.
The spectral ratio between magnetic field and source signals analysed for each shot, evidenced amplitude attenuation versus distance that appears both frequency and site dependent. These preliminary results suggest that a careful modelling of the seismo-electromagnetic effects could represent a tool to a further characterization of the Solfatara geothermal system.

During a monitoring experiment in Southern Italy (Pollino area) our research group recorded several interesting electromagnetic signals associated to earthquake swarm events (Balasco et al., 2014). Over the past decade, the most important oil companies are investigating similar seismo-electromagnetic signals coupled to active seismic experiments as a new tool to detect and characterize fluids in depth.
The occurrence of electromagnetic signals traveling as consequence of a mechanical source (natural or artificial) is well documented and physically founded in the frame of poroelastodynamic theory. Alternative generation mechanism, i.e resonant effects at cyclotron frequency of ions can be also found in literature.
At least two main aspects of the electromagnetic phenomena can be studied/verified:

1. EM wave velocity should be:
   - equal to the seismic velocity if the EM signal is a coseismic signal that travel with the P-wave;
   - significantly higher than seismic one if the EM signal travels independently from seismic wave front.

2. Resonant effects between seismic wave passage and cyclotron frequency of ions contained in the pores (inductive effects due to the presence of the Earth's magnetic field).

In order to explore these phenomena, during the RICEN experiment three magnetotelluric stations (electrical and magnetic variable fields) were installed. All of the three stations were continuously recording during the night too.
We analysed the results related to the artificial vibroseis source working inside the Solfatara, where it is well known that fluids play a key role. To match the frequency content of the artificial source, in each site we recorded at the highest sampling rate of the MT equipment (500 Hz).

In the following we deal with some steps of the processing of electromagnetic data developed ad-hoc for this experiment.
For a rapid detection of the eventual EM signals, a wavelet analysis was performed on each EM channel

recorded in a time window including the seismic shot events and at scales including the vibroseis frequency band. In the frequency band 16-32 Hz, the presence of a significant response in the magnetic components was evidenced; notwithstanding the presence of the power lines noise at 50 Hz, the response strength is well above the variance of the background magnetic signals in the same frequency band,. In order to better appreciate the closeness of the magnetic response to the seismic source, the power lines (50 Hz and harmonics) effects have been estimated by a least-square nonlinear fitting and then removed from the magnetic time series. The figure below shows the result of this step of analysis.

Repeating this procedure on the magnetic signals recorded for each shot during the above-mentioned two-day RICEN experiment, we verified that measurable signals are associated to each shot in the magnetic field components. The effects on the electrical field components are more difficult to detect.

The spectral ratio between magnetic field and source signals, analysed for each shot, evidenced amplitude attenuation versus distance that appears also to be frequency dependent. These results confirm a close link between the magnetic response and the seismic source used during RICEN experiment.

Standing the analyses done on the data recovered from the three MT stations in correspondence of more than 200 shots, a more ambitious goal could be pursued, such as to obtain an electromagnetic velocity tomography.

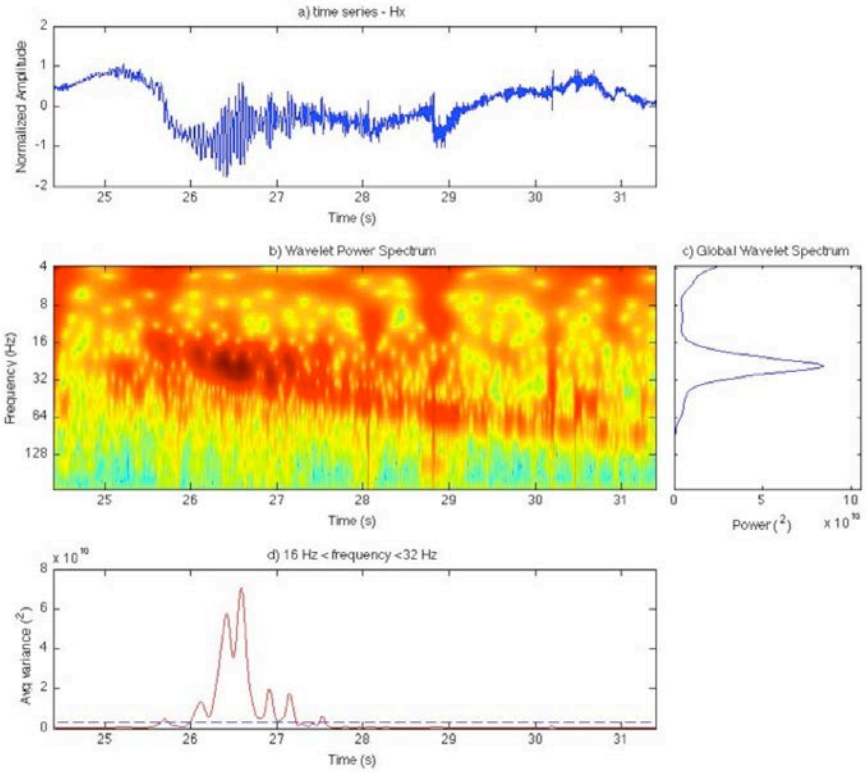

Figure 1. Site 2- (a) Power-line harmonics filtered magnetic field component Hx (7 s time-window). (b) Local Morlet power spectrum of (a); c) Global Morlet Spectrum; d) local spectrum averaged in the frequency band 16-32 Hz.

Signature of magmatic processes in ground deformation signals from Campi Flegrei

Matteo Bagagli, Chiara P. Montagna, Antonella Longo, Paolo Papale

Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Pisa, Pisa, Italy

Arrival of volatile-rich magmas from depth into already emplaced, evolved reservoirs has been documented as a possible trigger for past eruptions at Campi Flegrei. Being able to identify such processes in the geophysical records is of primary importance for the evaluation of the volcano's state, in order to improve our forecasting abilities. Numerical simulations of the convective and mingling dynamics that results from the arrival of deep magma into shallow chambers have been carried out, describing the space-time evolution of the physical properties of the fluid mixture. The results in terms of pressure and stress variations at the reservoir boundaries are propagated in the surrounding rock media to obtain the forward-modelled synthetic ground deformation signal on the whole frequency spectrum, from quasi-static to the seismic band. Wave propagation is performed by means of Green's function integration, considering a homogeneous half-space; this assumption is justified by the very low frequencies that dominate the spectrum, in the ultra-long period band (ULP: 10^{-4} - 10^{-2} Hz). Such low frequencies are not easy to identify in common volcano monitoring instrumentation. At Campi Flegrei, a network of high-sensitivity borehole dilatometers and underground long-baseline tiltmeters has recently been installed and is now fully operational, providing a unique possibility to detect ultra-long period oscillations. Records from tiltmeters during recent mini-uplift and increased unrest episodes, such as earthquake swarms and increased hydrothermal activity, have been analysed in order to identify patterns that may indicate magma recharge from depth. Comparison of the processed ground deformation signals recorded by the tiltmeters and the synthetics reveal remarkable similarities in terms of seismogram shape and frequency content (Figure 1). These preliminary results show the potential for a combined analysis of forward-modelled signals and monitoring records to improve on our ability to detect variations in the state of the volcano and thus to forecast its evolution.

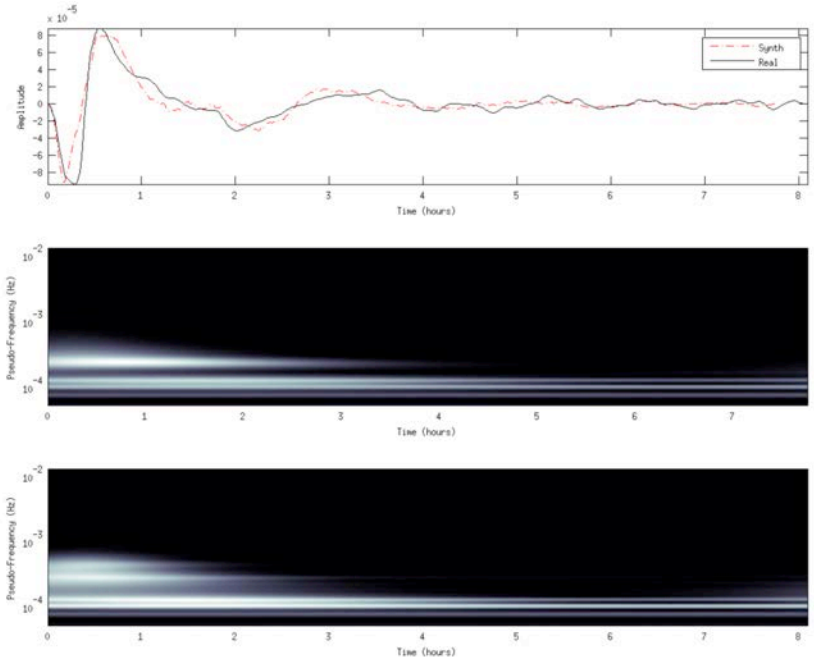

Figure 1. Trace Comparison. From top to bottom: Time Series comparison (8 hr), synthetic spectrogram, real spectrogram.

CO_2 flux changes induced by a vibratory seismic source at Solfatara (Phlegrean Fields, Italy)

Marceau Gresse[1], Jean Vandemeulebrouck[1], Svetlana Byrdina[1], Giovanni Chiodini[2], Pier P. Bruno[3]

[1]*Institut des Sciences de la Terre, CNRS-Universite de Savoie, Chambéry, France*
[2]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Bologna, Bologna, Italy*
[3]*The Petroleum Institute, Abu Dhabi, United Arab Emirates*

Solfatara, the most active crater of Phlegrean Fields is characterized by a fumarolic activity and an intense diffuse degassing. The total CO_2 release from diffuse degassing processes at Solfatara and its surroundings (~1.4 km^2) was estimated at 1000 t/d to 1500 t/d from 1998 to 2010 [Chiodini et al., 2010]. In addition, recent measurements of gas flux from the three main fumaroles of Solfatara that were performed in January 2013 indicated a total CO_2 output of up to ~600 t/d [Aiuppa et al., 2013]. In May and November 2014, during a seismic experiment (RICEN) in the frame of the MED-SUV European project, a Minivib vibratory seismic source was used to generate a frequency modulated seismic signal (three 15-s-long sweeps f=5-125 Hz) at different points of Solfatara. We performed CO_2 flux measurements with an accumulation chamber at a few meters from the seismic source during the vibrations in order to assess the potential impact of seismic waves on CO_2 degassing.

We obtained the following results:

- On many points, the vibrations induce a dramatic increase in the CO_2 diffuse degassing, with a flux that almost doubles during the seismic vibrations and returns to previous values afterwards.
- In low-flux areas or at a distance > 10 m from the vibroseis, no effect is observed. Evidence of a seismic amplitude threshold, and effect of the gas pore pressure.
- Maximum flux is reached after few seconds of vibrations, indicating the extra volume of CO_2 comes from a very shallow depth.
- When comparing the effects of the 3 successive vibrations, the amplitude of induced changes generally decreases over time, indicating the volume of extra CO_2 involved is very limited.
- Flux perturbations stop when vibrations stop: The effect is transient and the process dynamic.

The observed CO_2 flux increase can be interpreted as resulting from the release of gas during decompaction of a very thin (centimetric) surficial layer produced by the seismic vibrations.

A perturbative approach for the modelling of short-term fluid-driven ground deformation episodes on volcanoes: the case of Campi Flegrei caldera (Italy)

Zaccaria Petrillo[1], Luca D'Auria[1], Annarita Mangiacapra[1], Giovanni Chiodini[2], Stefano Caliro[1]

[1]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Napoli - Osservatorio Vesuviano, Napoli, Italy*
[2]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Bologna, Bologna, Italy*

We developed a numerical time-dependent inverse method, which allow retrieving the flow rate of fluids injection in hydrothermal systems by using the observed ground deformation. Our method works under the hypothesis that short-term ground uplift episodes (T<5years) depend on injection of volcanic fluids in the hydrothermal system. We demonstrate that, under general hypothesis, a perturbative approximation, in a neighbourhood of a steady state, of a thermo-fluid dynamics system, allows the use of a simple linear approach based on numerical Green's function. The fundamental assumption for the linearization is that the temperature variations of the system (including the source cells) and the phase changes of the fluids are negligible. These hypotheses allowed us to use a linearized Darcy equation to construct an empirical Green's function that linearly connects the evolution of the deformation field to the injected fluid rate that is we used the theory of the linear time-invariant causal filters. The thermo-fluid dynamics modelling has been applied to a 3D permeability and porosity model of Campi Flegrei caldera (CFc) and has been used for calculate both the steady state and the numerical empirical temporal Green's function (netGf). We have modelled ground deformation by computing the elastic response to the injection at depth of pressurized hot volcanic fluids (CO2/H2O mixture), taking into account both the poroelastic and the thermoelastic strain. In particular, the pore pressure calculated by the Tough2 simulator, in our approach is the main responsible for the short-term ground uplift episodes. We have calculated the deformation in a 3D tomographic elastic model of the CFc, by COMSOL-Multiphysics with the pressure acting as isotropic stress in the 3D mesh. The thermo-elastic strain has been calculated by the thermic expansion coefficient [Mc Tigue, 1986] and by COMSOL-Multiphysics. To retrieve the location and the extension of the injection area we have compared the deformation calculated as the response to an injection delta like (time dependent) in the source cells with that observed by the SAR images. We have searched the minimum misfit, exploring the deep part of the caldera, imposing the sources to be aligned and connected (a fracture like structure) and living the length, the orientation and the barycentre free. In particular, we have imposed the source cells to be synchronous and to have the same magnitude. In this way we have found a NW-SE elongated source with a length of about 3 km, placed at about 2400 m of depth, in the middle of the caldera. This fracture like source has been used to construct our netGf, that is, the deformation response of the surface (as function of time) to a synchronous single short injection in the source cells. The inverse method has been tested on a synthetic dataset, showing the capability of retrieving the flow rate pattern over temporal intervals up to about 25 years. We have applied the method to the years 1987-2013, during which the caldera has shown repeated unrest episodes, evidenced by both geophysical and geochemical data. Applying the inverse method we have found a good agreement between the measured and the estimated temporal deformation patterns. Results indicate a tight correlation between short-term ground uplift episodes and fluid injection rates, in the last 25 years at Campi Flegrei caldera.

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WP5

Talks

The magma storage capacity of Etna plumbing system: updated estimate from lava compositional changes in the last four decades

Patrick Allard[1,2], Rosanna Corsaro[2], Nicole Métrich[1,3]

[1]*Institut de Physique du Globe de Paris, Paris, France*
[2]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania - Osservatorio Etneo, Catania, Italy*
[3]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Pisa, Pisa, Italy*

Deciphering the magma plumbing system of a volcano is crucial to improved understanding and forecasting of its eruptive behaviour. Mount Etna is one of the most active basaltic volcanoes on Earth, built upon a 20-km thick continental crust at the collision boundary between the African and Eurasian plates. Seismic imaging indicates the presence a huge plutonic body in its sedimentary basement, as well as molten magma bodies ponding at main lithological discontinuities in the upper 10 km of the crust. However, limitations in spatial resolution still hamper accurate size estimate of these molten magma bodies. Here we use the remarkable evolution of Etna lavas over the last four decades (progressive enrichment of alkali and ^{87}Sr since the early seventies) to provide an updated estimate of the magma storage capacity of Etna's feeding system. Temporal changes in K_2O/Th, Rb/Th and $^{87}Sr/^{86}Sr$ ratios - unaffected by magma differentiation processes - tracks the replenishment of Etna's plumbing system by a new, more alkaline and more radiogenic basaltic magma that has gradually mixed with the former resident magma and promoted a sharp increase of the lava extrusion rate. In some occasions (e.g. 1974, 1998, 2001-2002) this new magma could reach the surface without pre-eruptive homogeneous mixing in the main storage cell, leading to the highest eruption rates. Such variations indicate a complex storage system, made of sills and dykes, in which some magma batches can either remain preserved for a significant time span or propagate independently of the central volcano conduits. Since 2005 the composition of Etnean products suggests that the influx of new magma might have either temporarily stopped or definitely ended. Combining these geochemical changes with the cumulative erupted and degassed magma volumes, we re-estimate the overall magma storage capacity beneath Etna. The figure obtained is larger than previous estimates and could be usefully compared with the results of recent seismic tomography realized within the framework of MED-SUV project.

Settling dynamics of natural ash particles: insight from laboratory high speed imaging

Elisabetta Del Bello[1], Daniele Andronico[2], Antonio Cristaldi[2], Ulrich Kueppers[3], Tullio Ricci[1], Piergiorgio Scarlato[1], Simona Scollo[2], Jacopo Taddeucci[1], Alix Vu Duc[4]

[1]*Istituto Nazionale di Geofisica e Vulcanologia, Roma 1, Roma, Italy*
[2]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania - Osservatorio Etneo, Catania, Italy*
[3]*LMU, Earth Sciences, Muenchen, Germany*
[4]*Universitè Catholique Louvain, Belgium*

Existing experimental and numerical models of ash sedimentation from volcanic plumes consider aerodynamic properties of particles as a function of their shape, density and size. However, rather than individually, particles are often observed to settle through zones of high particle concentration associated with gravitational instabilities where sedimentation is controlled by the properties of the bulk down-flow of settling particles. In order to investigate the differences in the aerodynamic behaviour of ash particles when settling individually or in mass, we performed systematic large-scale ash settling experiments. Natural basaltic ash from Etna (Italy, sampled in July 2014) and trachytic, pumiceous ash from Laacher See (Germany, 12.900 y BP), in the classes 125-500 μm and 500-1000 μm, respectively, was used as starting material. For each class, we released 40-500 g of sample from a height of 5 m with different, controlled volumetric flow rates, in an unconstrained open space and at minimal air movement. All experiments were recorded with a high-speed camera at 2000 fps. After release, particles were observed to cluster, leading to locally enhanced fall velocities. High-speed imaging, manual and automatic tracking analyses were used to provide full characterization of particle settling dynamics as a function of particle concentration in the flow, density and particle size. The measured settling velocities of individual particles increase with increasing particle concentration. This suggests that particle dispersion during fallout may be one reason explaining larger than theoretical depletion rates of fine particles from volcanic ash clouds.

The Tomo-Etna seismic experiment. Past, present and future

Jesús M. Ibáñez[1] & the UGR[1] and INGV-OE[2] research teams

[1]*Universidad de Granada, Granada, Spain*
[2]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania - Osservatorio Etneo, Catania, Italy*

The TOMO-ETNA experiment was focused on the base of generation and acquisition of seismic signal (active and passive) at Mt. Etna volcano and surrounding area in order to obtain a seismic tomography of Mt. Etna volcano and surrounding areas. The active phase of the experiment started in June 2014 and finished in November 2014 and includes marine and on land activities. Marine activities include Reflection and Refraction experiments (generating active seismic signals using air-guns), bathymetric measurements, magnetic surveys and submarine robot image. Active and passive seismic data were recorded by 108 3-component short-period seismic stations, 17 high resolution broadband seismometers, 25 OBSs and around 70 seismic stations from the INGV permanent network. Offshore activities of the TOMO-ETNA experiment were completed with the support of four oceanographic and military vessels: Sarmiento de Gamboa (CSIC-UTM, Spain), Aegaeo (HCMR, Greece), Galatea and Levanzo (Italian Navy). Offshore activities began on June 24, with the deployment of 22 Ocean Bottom Seismometers (OBS) in the Ionian and 5 OBSs in the Tyrrhenian Seas by the Gamboa and the Galatea. Two seismic exploration techniques were employed as part of this experiment, Wide Angle Seismic, June 27-July 6; WAS and Multi-Channel Seismic, July 11-17 and November 20-26; MCS. Around 40,000 air gun shots were fired by the Gamboa during both experiments. MCS profiles covered a length of about 1300 km. The second cruise with the Aegaeo vessel was scheduled to better detail the geological features of the study area through the acquisition of high resolution (HR) MCS profiles; they were acquired about 850 km of seismic lines in the Tyrrhenian and 180 km in the Ionian seas.

The Mt. Etna and surround areas preliminary p-waves seismic tomography

Alejandro Díaz-Moreno[1] & the UGR[1], IGP-Novosibirsk[2] and INGV-OE[3] research teams

[1]*Universidad de Granada, Granada, Spain*
[2]*IGP-Novosibirk*
[3]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania - Osservatorio Etneo, Catania, Italy*

The seismic tomography of Etna volcano is one of the main objectives of the TOMO-ETNA seismic experiment, using active and passive data. This experiment performed in June-November 2014 included data recorded by 108 3-component short-period seismic stations, 17 high resolution broadband seismometers, 25 OBS seismometers and around 70 seismic stations from the INGV permanent network. These data base include more than 2×10^6 first seismic arrivals (P and S waves). The data base contains air-gun shots and natural seismo-volcanic occurred activity during the period of the experiment. The first step of the tomographic inversion is the determination of the time of the first arrivals of all seismic signals in the maximum number of seismic stations. A manual procedure could imply years to finish the work. Additionally, the manual revision will have difficulties using signals with low signal-to-noise-ratio.

Task 5.4 models and software

José Fernández[1], Marco Aloisi[2], Alessandro Bonforte[2], Flavio Cannavò[2], Virginie Pinel[3]

[1]*Institute of Geosciences, CSI-UCMC, Madrid, Spain*
[2]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania - Osservatorio Etneo, Catania, Italy*
[3]*ISTerre, Université de Savoie, IRD, CNRS, Campus Scientifique, Le Bourget du Lac F73376, France*

This Task is devoted to sharing data formats, computer and modelling tools (from algorithms to computer codes). The new developed codes, methodologies and results will be implemented in the multidisciplinary interoperable infrastructure of the project (see WP3, Task 3.4). They will also share characteristics with those developed in the WP4. We present the new results obtained during the second year of the MED-SUV project in the different not concluded Sub-Task: 5.4.2 - Consensus 3D model of Etna; 5.4.3 - Local scale models: dike, faults and landslides; 5.4.4 - Global scale models; and 5.4.5 - Near real time deformation modelling.

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WP5

Posters

MED-SUV project: New results and ongoing activities of WP 5 - Task 5.1. Characterization of the threatening phenomena from space and ground

Susanna Falsaperla[1], Tiziana Apuani[2], Mauro Coltelli[1], Franck Donnadieu[3], Horst Langer[1], Eugenio Privitera[1], Giuseppe Puglisi[1]

[1]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania - Osservatorio Etneo, Catania, Italy*
[2]*Università degli studi di Milano, Milano, Italy*
[3] *Université Blaise Pascal - Observatoire de Physique du Globe de Clermont-Ferrand, Clermont-Ferrand, France*

The mitigation of volcanic hazard on an active volcano like Etna, Italy, requires an in-depth characterization of threatening phenomena from space and ground. To contribute to hazard mitigation efforts, the Task 5.1 of the European project "MED-SUV" (Grant Agreement n. 308665) has focused on phenomena such as cone-forming and lava flow emplacement, volcanic plume and eruptive products, degassing processes, and landslides, analysing their characteristics, duration and spatial dimension. Data mining tools have been made available to tackle a variety of classification and pattern recognition problems. Modelling and field experiments were also carried out on past and recent volcanic activity. In particular, test cases of past eruptions selected from the dataset of images, acquired by the "Etna NETVIS" since 2005, have been analysed with the aim of defining the geometry of lava flows for improving modelling and interpretation of lava flow emplacement. For the study of the volcanic plume and eruptive products, a relevant result was the development of a method of spatio-temporal integration of radar parameters measured in real-time to retrieve the total mass and flux of pyroclasts. To refine this method, a proxy proportional to the relative mass loading - correlated with the ash plume height - was derived. On-going research focuses on dynamic aspects of the explosive volcanic activity from short (second) to longer (cycles of eruptive episodes) time scales using continuous measurements of tephra reflectivity and velocity close to the source. In addition, to retrieve accurate DEMs and volumetric information of proximal products (tephra cones, lava flows) from multi-view photogrammetry, tests were carried out in July 2014. A field test on the three cones of Monti Silvestri (Etna) benefited from a drone infrared imagery.

As a contribute to flank dynamics evaluation and hazard assessment, a landslide susceptibility map at 1:10.000 scale of the north-eastern flank of Mt. Etna was produced, covering 168 km^2. The map covers the area of the transtensive Pernicana Fault system, encompassing a few documented mass movements and landslides. Among the semi-quantitative approaches proposed in the literature to obtain the regional distribution of potentially unstable slopes, the present research combines the Rock Engineering System (RES) methodology with parameter zonation mapping in a GIS environment. It was also traced the areal distribution of potentially unstable slopes based on a detailed, site-specific study of the factors predisposing for landslide.

The data mining tools available in the framework of Task 5.1 of the MED-SUV project allow us to tackle pattern recognition problems with supervised or unsupervised classification, considering various measures of similarity. Recent applications concern seismic data, along with the petrographic composition of rock, and in-soil radon emission. Additional software was developed improving existing schemes of automatic alert based on volcanic tremor data, establishing a voting procedure where each seismic station contributes to the decision whether or not to flag a criticality. Improved visualization tools also allow us to represent on map the development in time of tremor characteristics at the permanent seismic stations located on the volcano.

Finally, in mid-July 2014, an experiment was carried out at the summit of Etna, involving 40 researchers/technicians of different institutions from Italy, Germany, and France. During this experiment, we acquired multi-parametric (geophysical, geochemical and volcanological) data on the degassing processes at the North-East Crater (NEC), as well as degassing and eruptive activity at an eruptive fissure (EF), opened

on 5th July 2014 at the base of the NEC. Several kinds of studies are currently in progress: i) analyses of signals recorded by the permanent networks, in order to get a general framework in a long time period; ii) analyses of the explosions at the vents of EF recorded by microphones, seismometers and high-speed cameras, with the aim to investigate their inter-times and amplitude, the acoustic source location, the dynamics of the bomb ejections, as well as the explosion waveform variability; iii) the comparison among geochemical, thermal camera images and seismo-acoustic data in order to assess the partitioning of erupted mass flux between lava and pyroclasts, to compare the total erupted "solid" flux with the amount of degassed magma at EF and NEC as obtained from the SO_2 flux, and to compare these measurements with the seismic and acoustic parameters.

Multi-parametric characterization of multivent strombolian activity

Eugenio Privitera[1], Andrea Cannata[1], Elisabetta Del Bello[2], Juan Jose Pena Fernandez[3], Tullio Ricci[2], Piergiorgio Scarlato[2], Mariangela Sciotto[1], Joern Sesterhenn[3], Jacopo Taddeucci[2]

[1]Istituto Nazionale di Geofisica e Vulcanologia, , Sezione di Catania - Osservatorio Etneo, Catania, Italy
[2]Istituto Nazionale di Geofisica e Vulcanologia, Sezione Sismologia e Tettonofisica, Roma, Italy
[3]Technische Universitat, Berlin, Germany

On 5th July 2014, an eruptive fissure (hereafter referred to as EF) opened at the base of the North-East Crater (NEC), giving rise to both strombolian and effusive activities that carried on up to the first days of August 2014. In the framework of MEDSUV project, a multi-parametric experiment was performed in mid-July, with the aims to study degassing processes at NEC, and to investigate the degassing and eruptive activity at the EF. During the experiment, the explosive activity at EF was fed by two vents (see Figure 1). We deployed near these active vents broadband seismometers, microphones (recording in both infrasonic and audible bands), a high-speed video camera, and a thermal camera. In addition, the seismo-acoustic data were also recorded by the permanent seismic and infrasonic networks, run by INGV, Osservatorio Etneo - Sezione di Catania. In this work, in order to characterize the EF explosive activity, we performed the following analysis: i) spectral analysis of both seismic and acoustic data; ii) computation of seismo-acoustic energy and its partitioning; iii) investigation on the inter-times to investigate the recurrence behaviour of the infrasound events and then of the explosions; iv) classification of the infrasonic waveforms to divide the explosions into groups of similar events; v) location analysis of the acoustic sources by array techniques, to separate the acoustic contributions of the two active vents; vi) elaboration of visible and thermal images to characterize the explosive activity. Finally, the integration of the seismic, acoustic, and video results allowed us to get insights into the source mechanisms of the explosive activity.

Doppler radar observations of the 2011-2014 lava fountain activity at Etna

Franck Donnadieu[1,2], Valentin Freret-Lorgeril[1], Ariel Provost[1,2], Patrick Freville[2], Claude Hervier[2], Mauro Coltelli[3], Michele Prestifilippo[3], Simona Scollo[3]

[1]*Université Blaise Pascal Clermont-Ferrand, Lab. Magmas et Volcans, Clermont-Ferrand, France*
[2]*Observatoire de Physique du Globe de Clermont-Ferrand (OPGC), Clermont-Ferrand; France*
[3]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania - Osservatorio Etneo, Catania, Italy*

Since 2011, Etna's New SE Crater has shown recurrent cycles of eruptive episodes including Strombolian activity evolving into lava fountaining feeding ash and lapilli plumes, sometimes over 9 km a.s.l.. Hazards generated to air traffic, infrastructures like Catania's airport, and surrounding population are important. To help in early all-weather monitoring of surface pyroclastic activity at Etna's summit craters, INGV-Catania has been operating a Doppler radar of the Observatoire de Physique du Globe de Clermont-Ferrand (http://wwwobs.univ-bpclermont.fr/SO/televolc/voldorad/) from the Montagnola station (3 km south from the summit craters) since July 2009. Being fully integrated into the instrumental network, it captured over 40 eruptive episodes of the New SE Crater. In addition to its capacity of detecting explosive activity, radar recordings give access to the eruption intensity, to the timing of the Strombolian to lava fountain transition, and to the duration of the paroxysmal phase. As a first step toward quantifying pyroclastic emissions, we have developed a method of spatio-temporal integration of radar signals, based on the product of the backscattered power and radial velocity measured in real-time. These datasets provide a proxy for the (relative) total mass and instantaneous flux of the erupted pyroclasts, which correlate well with the ash plume height. Therefore, this radar mass proxy could be used in real-time monitoring. Absolute quantification of mass loading parameters is complicated by the lack of data on the grain size distribution at the source, the inclination of activity out of the beam, the strong influence of wind on weak plumes. The fraction of fine pyroclastic material transported in the atmosphere, causing most of the hazards, is also poorly known, whereas of crucial importance to the input of tephra dispersal models and to risk mitigation. By providing datasets of power and velocity at about 0.2s within successively probed volumes of the beam, this radar turns out to be also a powerful method to investigate the dynamics of explosive activity at short timescales close to the source, some examples of which will be shown.

Drone-based remote sensing applications for studying and monitoring volcanic environments: a case study on Mount Etna

Philippe Labazuy, Raphaël Paris, Franck Donnadieu

Laboratoire Magmas et Volcans, Université Blaise Pascal - CNRS -IRD, OPGC, Clermont-Ferrand, France

There is growing evidence that Unmanned Aerial Vehicles (UAVs) will become relevant tools for the study and the real time monitoring of volcanic activity in harsh environments. In the framework of the MEDSUV WP5.1.5 program, we planned to test remote sensing applications for remotely study volcanic environments. The initial objectives of the UAV experiment performed at Etna in July 2014 were to qualify ground- and drone-based multi-view photogrammetry of the new SE Crater (NSEC) for monitoring, including quick construction of high resolution (HR) DEMs, volume estimates of tephra cones and close infrared survey to help monitoring activity. Due to bad weather conditions and to volcanic activity, we refocused our experiments on safer targets in order to improve the feasibility of the methods for monitoring purposes. Survey of the NSEC was limited to a ground-based coverage of the southern flank, using high-resolution (Nikon D3X 24 Mpx) camera. We then achieved a multi-view drone acquisition of the Monti Silvestri. The drone is a Mokrokopter octopter (multirotor with 8 engines) equipped with an 8 Mpx Sony Nex 5R camera, operated at a height above the ground of about 150m using pre-programmed GPS positioning. Drone-based and ground-based multi-view photogrammetry acquisitions both allowed calculating 20cm resolution DEMs, with planimetric and altimetric accuracy of about 5cm and 10cm respectively. We also tested and operated mobile infrared videos (ground- and drone-based) to complement monitoring of eruptive activity from a fissure at the base of NE crater. This validation study clearly illustrates the potential applications of UAVs for volcanic environment monitoring. We also demonstrated that high resolution DEMs can be obtained rapidly and at low cost using ground-based HR photos or camera on-board drone. Potential applications to monitoring from reiteration of surveys include volume estimates of proximal products (growing tephra cone, ballistic fallout, lava flows), providing accurate quantitative information that can be used to better assess instability and document time evolution in 3D. This methodology may also be applied for characterizing at-vent particle size distribution during explosive activity. Low cost infrared cameras can be used from close on ground or on-board drones to improve the characterization of the ongoing activity (location, channelization, activity spots, etc.) in complement to permanent monitoring network information, and to acquire ortho-rectified and georeferenced aerial thermal imagery which can be associated to high resolution DEMs.

Spatio-temporal evolution of the creep on the faults of Etna observed with ERS and ENVISAT interferometry

Sofia Mitoulaki[1], Konstantinos Derdelakos[1], Francesco Guglielmino[2], Panagiotis Elias[3], Alessandro Bonforte[2], Giuseppe Puglisi[2], Isaac Parcharidis[1], Pierre Briole[4]

[1]*Harokopio University Athens, Athens, Greece*
[2]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania - Osservatorio Etneo, Catania, Italy*
[3]*National Observatory of Athens, Athens, Greece*
[4]*Centre National de la Recherche Scientifique, Ecole Normale Supérieure, Paris, France*

During the last twenty years, SAR interferometery and GPS have shown that Etna is characterized by a relatively stable west flank and a mobile east flank. The boundary between stable and mobile areas is well defined to the north with a unique fault ensuring the transition, the left lateral Pernicana fault. The south boundary is more complex with several right lateral faults, the Mascalucia fault, the Trecastagni fault, S. Leonardello and Timpe fault system. Those faults are well imaged by SAR interferometry and they have been described and discussed in several articles. A coarse analysis of the different data sets indicates that the motion along those faults has not been steady with time during the last twenty years, with periods faster than others. The seismicity on those faults is also known not to be steady with time. Some of them produce a well visible topography, e.g. the Pernicana, while others do not produce a clear topography, e.g. the Mascalucia fault. The depth of those faults is not well established. They might cut only the volcanic products and not the sedimentary basement, and therefore allow the eastward motion of the recent (<300kyr) volcanic products pushed in the summit area by the episodic injection of dykes feeding the eruptions. We produced a series of interferograms using the AMI/ERS and ASAR/ENVISAT archive available from 1992 to 2010, with maximum baseline 250 m and maximum time span 4 years. Here we present our results obtained with the ascending track 129. A "hybrid" InSAR methodology was used, combining elements of conventional repeat-pass InSAR and PSI based on Single Value Decomposition (SVD) in order to obtain the least-squares solution for the phase time-series. Since SVD does not correct for spatially differential phase delays induced by atmospheric disturbances and in order to avoid the propagation of unwrapping errors in our final products we identified and excluded the questionable interferometric pairs. The effect of the atmosphere is not crucial for investigating localized deformation at creeping faults, but it can be noticeable at the scale of the fault lengths. Using published maps of the faults and our interferometric products, we refined the location of the fault and we discuss the status of the transitions between faults. We calculated accurately the average slip velocities and compared with those published, and we also compared with the available GPS velocities. In the next step we shall analyse the time series derived from PS and SBAS inteferometry. For the Pernicana and both Mascalucia/Trecastagni fault, a specific PS processing method for non-urban areas will be used separately, starting from a multi-reference stack of inteferograms. This technique is suitable for areas affected by non-uniform motion, fast line of sight (LOS) deformation rate and high decorrelation resulting in coherence loss over long time intervals.

Insights into the shallow plumbing system of Mount Etna from ^{210}Pb-^{210}Bi-^{210}Po disequilibria in the volcanic plume

Luca Terray[1], Pierre-Jean Gauthier[2], Giuseppe Salerno[3], Tommaso Caltabiano[3], Alessandro La Spina[3], Pasquale Sellitto[1], Salvatore Giammanco[3], Letizia Spampinato[3], Pierre Briole[1]

[1]*Centre National de la Recherche Scientifique, Ecole Normale Supérieure, Paris, France*
[2]*Laboratoire Magmas et Volcans, Université Blaise Pascal - CNRS -IRD, OPGC, Clermont-Ferrand, France*
[3]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania - Osservatorio Etneo, Catania, Italy*

The study of ^{210}Pb-^{210}Bi-^{210}Po disequilibria in the plume of Mount Etna has proved very relevant in constraining the shallow degassing of the volcano. One noteworthy attainment was to set time constraints on the transfer of magmatic gases from a shallow degassing reservoir to the atmosphere. Nevertheless, there have been no measurements of ^{210}Pb-^{210}Bi-^{210}Po disequilibria in Mount Etna plume for twenty years, and within MED-SUV, we decided to resuscitate this study at Mount Etna in order to:

1. derive dynamical parameters related to shallow degassing processes (kinetics of gas transfer, magma residence time, volume of magma involved). We will use an improved geochemical framework based on the model proposed for Stromboli by Gauthier et al. [2000]. Among the improvements, we will consider the ingrowth of ^{210}Pb in the gas phase due to ^{222}Rn decay, a feature that has never been considered until now.
2. assess the relevancy of ^{210}Pb-^{210}Bi-^{210}Po measurements at safe distance from the active craters (>1 km). This would enable routine sampling of the diluted plume as part of the monitoring network.

A first field campaign took place between 11 and 22 May 2015. Due to intense eruptive activity at the New South-East Crater, the campaign was mostly focused on remote sampling between Torre del Filosofo and La Montagnola. A second campaign is scheduled in July 2015 in order to get gas samples from each summit crater of Mount Etna. Analysed ^{210}Pb-^{210}Bi-^{210}Po disequilibria will contribute to (i) getting a snapshot of the shallow degassing pattern, and (ii) comparing degassing trends of each crater whose activities have differed during the recent eruptions. In addition to the aerosol sampling for radionuclides, both UV and FTIR spectrometry observations are performed to constrain major elements and gas fluxes. Integration of all parameters should provide us with new insights into the degassing activity beneath Mount Etna.

Sulphur behaviour in Etnean magmatic system (Italy)

Emanuela Gennaro[1,2], Giada Iacono-Marziano[2], Andrea Rizzo[3], Michel Pichavant[2], Antonio Paonita[3], Marcello Liotta[3], Silvio Rotolo[1,3], Caroline Martel[2]

[1]*DiSTeM, Universitá degli Studi di Palermo, Palermo, Italy*
[2]*ISTO, UMR 6113 CNRS-Université d'Orléans, Orléans, France*
[3]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Palermo, Palermo, Italy*

Sulphur is an important volatile component of basaltic magmas and it is mostly dissolved as S6+ and/or S2- depending on the redox conditions. Enormous quantity of SO_2 (daily average of 3530 tons) are continuously discharged from Mount Etna. However it still remains to understand these high flows in term of the S origin (magmatic or crustal) and its behaviour during magmatic evolution (fractional crystallization, magma mixing, and vapour/melt fractionation). Our research combines the study of sulphur in natural olivine hosted melt inclusions with an experimental study on S solubility in hydrous alkali basalts at magmatic conditions.
We report new data of S and other volatile species (H_2O, CO_2, Cl, F) in melt inclusions, belonging to six of the most characteristic Etnean eruptions of the last 14 ky, from the oldest and most primitives (Mt. Spagnolo and FS eruptions) up to the recent paroxysm event of April 2013. These melt inclusions were entrapped at different depths inside the magmatic system (up to ~ 18 km, corresponding to a pressure of almost 5 kbar) as defined by H_2O-CO_2 contents. Sulphur content, evaluated by EMP and SIMS methods, reach 3600-4000 ppm in the most primitive melt inclusions of Mt. Spagnolo and 2006 eruptions (Fo87 and Fo80). Sulphide globules were observed in some melt inclusions of 2002/3, 2006, 2008 and 2013 products, but also in host olivine crystals, probably reflecting sulphide saturation of the melt during the entrapment of the melt inclusions. We therefore carried out IHPV experiments in Etnean mafic melts at sulphide saturation in order to investigate how the variations in S content observed in melt inclusions can be explained by the changes in magma composition and/or magmatic conditions (T-P-fO_2).

The deep plumbing system of Mt. Etna: temporal evolution detected by the study of sub-aphyric primitive magmas

Rosa Anna Corsaro[1], Nicole Métrich[2]

[1]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania - Osservatorio Etneo, Catania, Italy*
[2]*Institut de Physique du Globe de Paris - Geologie des Systemes Volcaniques, Paris, France*

Mt. Etna sub-aphyric primitive magmas are erupted during rare and highly explosive flank eruptions which were firstly called eccentric by Rittmann [1965], and have been recently renamed DDF, i.e. deep dike-fed eruptions by Corsaro et al. [2009]. These eruptions are uncommon in the history of Mt. Etna and occurred both in historical (1763, 1974, 2001 and 2002-2003 eruptions) and pre-historical times (eruptions of Mt. Spagnolo, Mt. Frumento delle Concazze, Mt. Maletto and FS Mg-rich tephra, from 15ky to 3540y).
DDF eruptions are driven by deeply-rooted magma intrusions which rapidly ascend and bypass Etna shallow plumbing system. Since the composition of the DDF-related magmas is poorly modified by pre-eruptive magmatic processes (i.e. fractional crystallization, mixing etc., their study represents a promising tool to investigate the dynamics of the volcano deep plumbing system and the processes of the mantle below.
A new petrologic dataset (petrography, major and trace element geochemistry) concerning six DDF eruptions has been combined with literature data, allowing evidencing that significant compositional changes affected DDF magmas over the last 15 ky. This chemical evolution is not gradual with time and is consistent with long-term magmatic processes involving both different melting degrees of a source region similar to the Hyblean mantle, and variable contributions of slab-derived components. Furthermore, short-term compositional variations, documented within the products of Mt. Frumento delle Concazze, have been attributed to local processes, such as fractional crystallization in the deep storage region of the plumbing system. Finally, the new data allowed getting insights into the composition of the un-erupted parental magma feeding the present-day activity of the volcano.

Geochemical evidences from He-Sr-Nd isotopes and trace elements of primitive products from Mt. Etna volcano

Alessandra Correale[1], Antonio Paonita[1], Mauro Martelli[1], Andrea Rizzo[1], Silvio G. Rotolo[1,2], Rosa Anna Corsaro[3], Valeria Di Renzo[4]

[1]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Palermo, Palermo, Italy*
[2]*Università di Palermo, Palermo, Italy*
[3]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania - Osservatorio Etneo, Catania, Italy*
[4]*Seconda Università di Napoli, Aversa (CE), Italy*

Some primitive products from Mt. Etna (spanning the last 15 kyr of the volcano history) were selected in order to better constrain the geochemical signature of the mantle source beneath the Sicilian volcano. In detail, Sr-Nd isotope and trace element analyses were performed on the bulk rocks of the studied samples whereas the fluid component was investigated for isotopic and elemental content of noble gases (He and Ar). Trace element and noble gas results highlighted the presence of a mantle source common to all of the investigated samples and compatible with a peridotite matrix veined by about 10% of clinopyroxenite. The wide range measured in the trace element geochemistry (i.e. Zr/Nb=2.81 - 4.98, Ce/Yb=35.02 - 66.90, La/Yb=15.36 - 35.52, Th/Y=0.17 - 0.43) of studied lavas could be attributable to a different degree of partial melting (up to 10%) of this common mantle source probably due to a variable fluid content. Coupling between trace element and Sr isotopes allowed hypothesizing that these fluids are inherited by a crustal contamination of the mantle source beneath Mt. Etna. On the contrary, He- and Sr- isotope decoupling is the consequence of the pre-eruptive addition of ^{4}He resulting from magma aging and/or crustal contamination of magma. The elemental and isotope composition of He and Ar reflects a bulk of fluid inclusions entrapped in a selected amount of crystals (1-2 g of olivines and pyroxenes). Considering that these fluid inclusions may have not been entrapped simultaneously, our measurements represent a mean of minerals having different crystallization histories in the plumbing system of the volcano. Thus, it is not currently possible to identify a path of magma depressurization and to assess the range of pressures at which those minerals crystallized (i.e., depths of magma stationing). In order to improve our knowledge, the next step of our research is to attempt in situ measurements of He and Ar in single fluid inclusions by Laser Ablation-Mass Spectrometry (LA-MS) technique. Anyway the low gas content of each single inclusion makes these measurements very challenging. To date, we performed some preliminary tests on experimental glasses (basalts and rhyolites, 2 Kbar pressure) bearing H_2O-CO_2-He and on clinopyroxenes from Hyblean mantle xenoliths characterized by pure CO_2 inclusions.

Advances in picking strategies based on the usage of polarization attributes

Luz García-Martínez & the UGR research team

Universidad de Granada, Granada, Spain

The seismic tomography of Etna volcano is one of the main objectives of the TOMO-ETNA seismic experiment, using active and passive data. This experiment performed in June-November 2014 included data recorded by 108 3-component short-period seismic stations, 17 high resolution broadband seismometers, 25 OBS seismometers and around 70 seismic stations from the INGV permanent network. These data base include more than 2×10^6 first seismic arrivals (P and S waves). The data base contains air-gun shots and natural seismo-volcanic occurred activity during the period of the experiment. The first step of the tomographic inversion is the determination of the time of the first arrivals of all seismic signals in the maximum number of seismic stations. A manual procedure could imply years to finish the work. Additionally, the manual revision will have difficulties using signals with low signal-to-noise-ratio.

Seismic anisotropy at Mt. Etna for the 2010-2011 seismic database

Lucia Nardone[1], Francesca Bianco[1], Lucia Zaccarelli[2]

[1]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Napoli - Osservatorio Vesuviano, Napoli, Italy*
[2]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Bologna, Bologna, Italy*

The methodology most commonly used to study the anisotropy in the crust is based on the analysis of the birefringence phenomenon affecting the shear wave (Shear Wave Splitting). When a shear wave enters in an anisotropic volume, splits into two (quasi) shear waves which have different velocity and different polarization directions, usually orthogonal. If the anisotropic volume is due to the presence of fluid filled aligned cracks or micro cracks (TIH transverse isotropy with horizontal axis of symmetry, or hexagonal symmetry anisotropy) is controlled by stress field acting on the area; however the crust may be also affected by anisotropy due to layering and shale (TIV transverse isotropy with vertical axis of symmetry) that, on the contrary, do not respond to changes in the acting stress filed. The characteristic parameters used to study the anisotropy of a medium are the time delay between the Fast and Slow waves (dt) and the polarization of the Fast splitted wave (LSPD linear split polarization direction). Since this direction is parallel or, at least, subparallel to the stress field direction, the study of anisotropy is an efficient tool to get information on the tectonic stress field in the Earth. The difference in time between the splitted waves is influenced both by the shape and the density of fractures causing the anisotropy. Therefore the measure can be used as an indicator of stress field intensity variations or of rapid changes of other conditions. In order to obtain information on the temporal variations of the splitting parameters in quasi-real time some codes for a semiautomatic analysis have been developed with the aim to rapidly use the obtained measurements as a monitoring tool for the stress field variations, especially for volcanoes. The previously described approach applied to the Mt. Etna to study both spatial characteristics and temporal variations of the anisotropic volume below the volcano. The starting dataset consists of 172 earthquakes recorded from 2010 to 2011 by the permanent monitoring network of INGV-OE (an example for the Z component is in Fig.1).

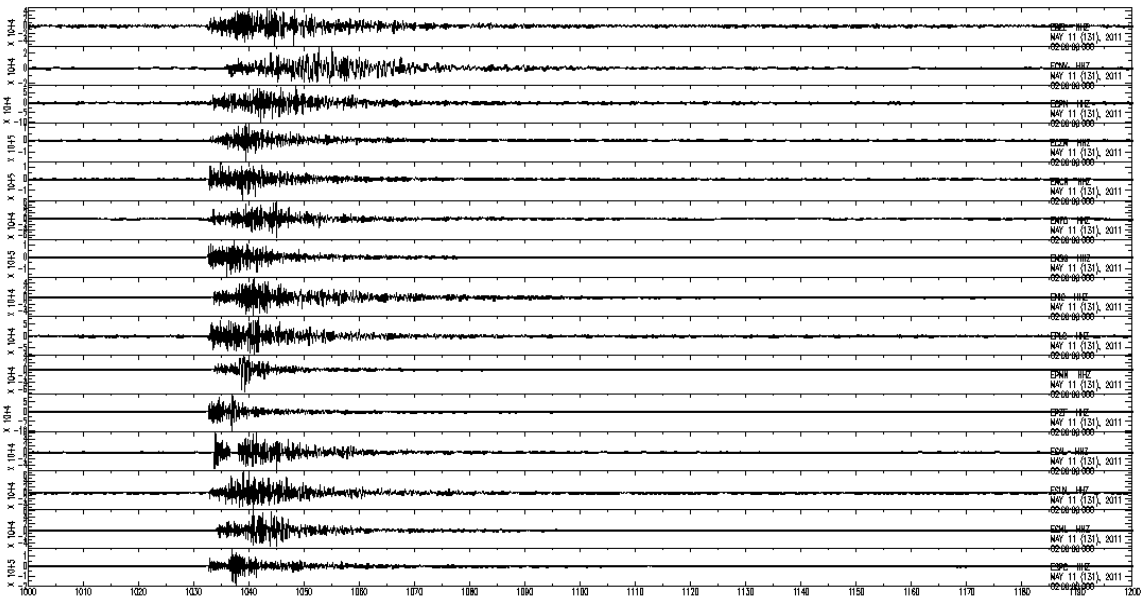

Figure 1. Vertical components of motion for an earthquake occurred on 05/11/2011.

The splitting parameter measurements are performed by applying a rigorous selection of seismic records (clear shear wave onsets and angles of incidence inside the shear wave window (0-35 degree)). The selected dataset is analysed using a semiautomatic analysis code SPY, applying the diagonalization of the covariance matrix and the method of cross-correlation. The algorithm requires as input selected event seismograms, their hypocentre locations, and P and S arrival times and, working in a semi-automatic way, defines the leading polarization direction LSPD (degrees from North) and dt. The results are checked in hodograms to avoid possible cycle skipping and other anomalous effects. Statistical tests on the parameters obtained are performed in order to consolidate the results achieved, interpreting them in terms of temporal and spatial variations of the volcanic activity.

Variability in composition and physical properties of the sedimentary basement of Mt. Etna, Italy

Sebastian Wiesmaier[1,2], Michael J. Heap[3], Stefano Branca[4], Albert H. Gilg[5], Ulrich Kueppers[1], Kai-Uwe Hess[1], Yan Lavallee[6], Donald B. Dingwell[1]

[1]Ludwig-Maximilians-Universität München, München, Germany
[2]GEOVOL, Universidad de Las Palmas de Gran Canaria, Canary Islands, Spain
[3]EOST, Université de Strasbourg, Strasbourg, France
[4]Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania - Osservatorio Etneo, Catania, Italy
[5]Technische Universität Muenchen, Muenchen, Germany
[6]University of Liverpool, Liverpool, United Kingdom

The sub-volcanic basement at Mt Etna (Italy) comprises thick sedimentary sequences. An understanding of the physical, mechanical, and microstructural properties of these sequences, and an appreciation of their variability, is important for an accurate assessment of the structural stability of Mt Etna. Here, we present a combined field and laboratory study in which we explore the extent of variability of the materials comprising the sedimentary basement of Mt Etna. To this end, we sampled twelve different lithological units that span the sediments of the Apenninic-Maghrebian Chain (from both the Silicide and Ionides sequences) and the Hyblean Plateau. X-ray diffraction analysis of the blocks collected show that calcite and quartz are the predominant mineral phases. Textural analysis highlights the wide variability in rock microstructures, with features such as the presence/absence of fractures or veins, pore size and shape, and grain size and shape varying tremendously between the samples. One consequence of this microstructural, textural, and mineralogical variability is that the different rock units are characterised by very different values of porosity, P-wave velocity, uniaxial compressive strength, and static Young's modulus. For example, strength and Young's modulus vary by a factor of twenty and an order of magnitude, respectively. Our study affirms the vast heterogeneity of the sub-volcanic sedimentary basement of Mt Etna and, on this basis; we urge caution when selecting potentially oversimplified input parameters for models of flank stability.

2-step magma propagation modelling: Application to the 2001 Mount Etna eruption

Virginie Pinel[1], Alexandre Carrara[1], Francesco Maccaferri[2], Eleonora Rivalta[2]

[1]ISTerre, Université de Savoie, IRD, CNRS, Campus Scientifique, Le Bourget du Lac, France
[2]1GFZ German Centre for Geosciences, Section 2.1, Telegrafenberg, Potsdam, Germany

We developed a two-step model of dike propagation where we first calculate a dike trajectory in 2D and secondly run a 1D dynamical model of dike propagation along this trajectory taken into account the influence of the stress field seen by the dike along this path. We tested this new approach using the 2001 dike event propagation that occurred at Mount Etna as described by Bonaccorso et al. [2010]. From 15 to 17 July 2001, deformation data recorded at Etna volcano show a dike emplacement at 500 m beneath the surface. This dike then propagated laterally towards the surface during 2 days before feeding an eruption located at a lateral distance of 1.4 km. The dike deflection (associated to a decrease of velocity) was interpreted as due to topography. Following Bonaccorso et al. [2010] we calculated the stress field induced by a topographic load of 1 km height and 1.5 km radius. We derived the expected dike path in case the stress field effect is dominant compared to the buoyancy. In this case the dike should follow the orientation of the main principal stress $\sigma 1$. Then we ran a 1D model of dike propagation [Traversa et al., 2010] along this path neglecting the dike curvature. We can observe a decrease of the dike velocity as soon as it enters the load stress field this velocity decrease occurs together with a dike thickness increase.

Dike-fault interaction with application to the 2000 intrusion at Miyakejima

Eleonora Rivalta[1], Francesco Maccaferri[1], Luigi Passarelli[1], Virginie Pinel[2]

[1]*GFZ German Centre for Geosciences, Section 2.1, Telegrafenberg, Potsdam, Germany*
[1]*ISTerre, Université de Savoie, IRD, CNRS, Campus Scientifique, Le Bourget du Lac, France*

Here we present (1) a numerical model of dike propagation and arrest and (2) a study on the focal mechanisms of dike-induced seismicity applied to the 2000 dike intrusion at Miyakejima, Japan. The 2000 Miyakejima intrusion shows several similarities with most dike intrusions at Etna: In particular, the trajectories and the dynamics of the dikes at Etna and Miyakejima have been observed to be strongly controlled by topographic loads [Bonaccorso et al., 2010; Maccaferri et al., 2015, in preparation] and to be strongly interacting with pre-existing strike-slip tectonic structures (for Etna, the Pernicana fault, see for example Ruch et al., [2013]). At Etna, numerous dike intrusions have occurred in recent times and a variety of mechanisms of emplacement and propagation were observed (vertically and horizontally propagating dikes in connection with the central conduit or eccentric, with a variable degree of interaction with the flank dynamics and with the pre-existing tectonics). In order to understand the physical mechanisms governing this complexity, comparisons with other dike intrusions at stratovolcanoes around the world are very useful. The work on the 2000 dike at Miyakejima clarifies some of the physical factors influencing dike propagation that also play a fundamental role at Etna. We studied dike arrest by developing a numerical model for the lateral propagation of a dike that is affected by topographic loads and large pre-existing pre-stresses faults. Our conclusion is that in order to explain both the arrest of the Miyakejima dike and the deformation measured by GPS stations, both topography and interaction with faulting are important factors, but the interaction with faulting played the largest role in arresting this dike. Moreover, we studied the 3D stress field induced by a dike by examining the group properties of the fault plane solutions from a catalogue containing about 1500 earthquakes induced by the Miyakejima dike and relating them to the stress field around a penny-shaped pressurized crack. We found that it is important to consider the fact that a real 3D dike in the field is shaped as a penny or elliptical crack, as rectangular dislocation models cannot explain the orientation of the focal planes of all induced earthquakes. The frequency-magnitude relation of the earthquakes, separated according to their type (normal faulting vs. strike-slip) shows that strike-slip earthquakes are distributed according to the Gutenberg-Richter relation with b~1, while the normal faulting group shows a poor fit with a GR model since it lacks large magnitude events.

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WP6

Talks

Elicitation experiment at Etna Volcano

Alfonso Brancato[1], Laura Sandri[2], Jacopo Selva[2], Warner Marzocchi[3]

[1]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania - Osservatorio Etneo, Catania, Italy*
[2]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Bologna, Bologna, Italy*
[3]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione Sismologia e Tettonofisica, Roma, Italy*

WP6 of MED-SUV European Project aims at showing how the improvement of the monitoring system may contribute to better volcanic hazard assessment and to bridge the gap between science, mitigation and preparedness of volcanic disasters. Therefore, scientists and decision makers are working together to optimise procedures for improvement their mutual information exchange. Advances in volcano monitoring and forecasting need multidisciplinary collaborative framework. In light of this, a Bayesian Event Tree (BET) approach was performed. A central element of the Bayesian paradigm is the use of probability distributions to describe all relevant unknown quantities, and interpreting the probability of an event as a conditional measure of uncertainty (on a [0, 1] scale) about the occurrence of the event in some specific conditions. The BET approach is formalized to the application of the BET_EF code which explores the space-time distribution of the volcanic activity of Mt. Etna. The code produces a probabilistic graphical model that expresses the joint distribution of a large number of interrelated variables. The definition of what is background vs anomaly and the interpretation of anomalies represent the core of the analysis, i.e., the selection of the parameters of interest, and the quantitative definition of anomalies. At Mt. Etna different previous pre-eruptive observations, with different timescales (from months to days/hours), are recorded. Nevertheless, subjectivity is often the feeling expression of an incoming event. To minimize such a feeling, an expert opinion can be formally used. Weighting of experts varies, but it is a fundamental part of the elicitation process, even though often equal-weighted procedures are still considered. For the present analysis, a consensus-based expert scoring scheme and an innovative expert elicitation method that uses a structured and iterative process for developing agreement are adopted. In this process, expert opinion is weighted on the basis of mutual recognition among experts expressed through a regularly repeated blind procedure.

In detail, for each node of the BET,

1. the reported scores and votes (in this latter case, all the experts have weights equal to 1) for all the selected parameters are plotted;

2. for each parameter (using scores and votes of previous point 1) average, median, and 10th and 90th percentiles of the selected thresholds are estimated; additionally, the coherence of the order relationship (increasing or decreasing trends for a fuzzy perspective, and equality for Boolean approach) is constantly verified.

A different setting regards the thresholds aimed to accept the selected parameters, being evaluated by considering marked slope changes, if they occur, in curves of previous point 1.

In April 2015, INGV Osservatorio Etneo (Catania) and Palermo Section experienced Elicitation I, which involved 40 (out of 58; ca. 70%) experts, who daily monitor Mt. Etna. Geophysical, geochemical and volcanological expertise is included. Experts selected parameters and relative critical thresholds at each node of the event tree. In this way the individual and collective specialist knowledge is more effectively exploited,

since the experts discuss and express themselves directly in their field of expertise: their knowledge enters the statistical model without the filter of personal sensitivity to probabilities. All the experts selected parameters, node by node, aiming at recognizing the magmatic unrest possibly leading to flank eruption, and forecasting relative occurrence, from panels arranged on a website (http://elicitazione-etna-lateral.bo.ingv.it/public/). We exploit the online procedure because of time for thinking and consulting bibliography during the elicitation and need of selecting only from a predefined list of parameters and of providing only numerical threshold. Results are immediate, thus giving the possibility for relative discussions and a feedback to the experts. Finally, possibility of repeating often the procedure without physical meetings speeds up the experiment. Regarding to the scores analysis (weights obtained from scores), it is roughly equivalent to votes analysis (equiprobability of the experts) for nodes 1 and 2, while significant differences appear at node 3. In particular, both at nodes 1 and 2 there seems to be a single parameter that has been selected by the majority of experts (among them, some of those with higher score), while all the other proposed parameters do not aggregate a large consensus and are selected by minorities. At node 3, it appears that the highest score's experts have voted a few unpopular parameters, while the most popular ones have a low total score (meaning that the low score's parameter has selected it). In the next future, we are planning to better explore the coherence among nodes, as well as different elicitations aiming to assess the monitoring parameters to be used in the BET_EF code.

Anticipating abrupt shifts in temporal evolution of probability of eruption

Jeremy Rohmer, Annick Loschetter

Bureau de Recherches Géologiques et Minières, French Geological Survey, Orleans, France

Estimating the probability of eruption by jointly accounting for different sources of monitoring parameters over time is a key component for volcano risk management. In the present study, we are interested in the transition from a state of low-to-moderate probability value and to the one of high probability value: the latter value generally supports the call for evacuation. This is exemplified in the figure below (top, left) by using the data of MESIMEX exercise at the Vesuvius volcano derived from the study by Marzocchi and co-authors in 2008. The generic step-like pattern of the eruption probability suggests the phenomenon of 'critical slowing down': this corresponds to a slow rate of return to equilibrium once a system has been slightly perturbed as it approaches the critical transition. A system approaching such a transition can be detected by changes in the properties of the time series, either in its correlation structure or in its variability. The former property can be captured by an increase in the autocorrelation at lag-1 (ACF1), which indicates that the state of the system has become increasingly similar between consecutive observations. Yet, a limitation of ACF1 is that it ignores changes in correlation structure at higher lags. An alternative is to rely on power spectrum analysis by investigating changes in the power spectra of a time series by estimating for instance the spectral ratio of the spectral density (DR) at low frequency (e.g. 0.05) to the spectral density at high frequency (e.g. 0.5): this can reveal changes in the complete spectral properties of a time series prior to a transition. Besides, increase in the autocorrelation goes in general in pair with a wide drift of the system around the stable state, which can be detected by an increase in the statistical moment like standard deviation (SD), skewness (SK) and kurtosis (KU) of the time series. Assuming that the bulletin of the monitoring parameters could be launched every hour, the application of the afore-described indicators showed that SD and DR both present a slightly rising temporal evolution followed by a steep change (break) marking the approaching abrupt change to a state of larger eruption probability as depicted in the figure. The time instant of this break varies between 2 to 4 hours ahead of the transition and between 58 and 60 hours (circa 2.5 days) ahead of the evacuation call (decided on October 21th, 5 pm after the eruption probability has reached values >80%). The robustness of this result was tested by conducting a Monte-Carlo-like approach, which proved to be conclusive. This importance of this additional lead time should be questioned from a crisis management perspective. In urban areas where evacuation is likely to take many hours due to expected road blockages and egress-critical bridges, any additional time can be of interest especially regarding the evacuation vulnerable groups, (e.g., sick and elderly people). When the state of the volcano indicates a low-to-moderate probability of eruption, the studied early-warning can justify decisions for placing different key services on a higher level of alert: for instance for emergency services or for public transportation services to commandeer auxiliary/additional transport means or even for shutting down safety-critical engineering systems. Balancing whether it is worthwhile to commandeer those actions in advance of four hours and the additional effort / cost for increasing the frequency of the monitoring bulletins could be addressed using the tools of cost-benefit analysis.

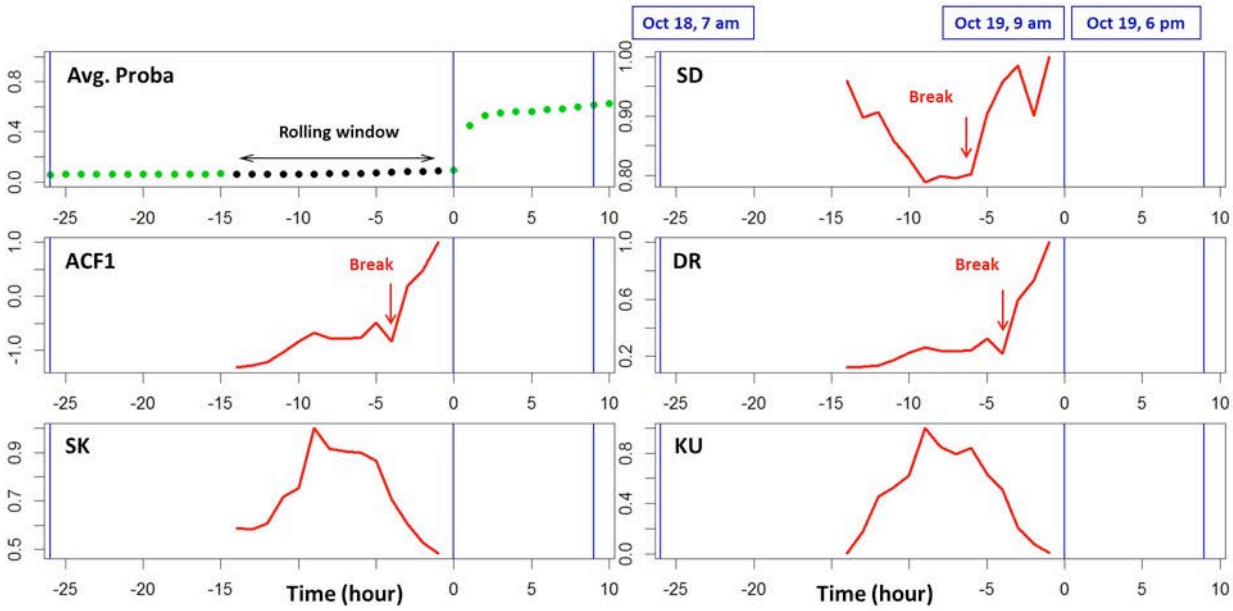

Figure 1. Temporal evolution of the simulated time series of average probability of eruption for the MESIMEX exercise with the different indicators SD (Standard deviation), ACF1 (autocorrelation function lag-one), DR (density ratio), SK (Skewness), KU (Kurtosis).

Three dimensional numerical simulations of volcanic plumes: particle non-equilibrium, turbulent entrainment and comparison with integral models

Matteo Cerminara, Tomaso Esposti Ongaro

Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Pisa, Pisa, Italy

Two dynamics of weak (mass eruption rate = 5e06 kg/s) and strong (m.e.r = 5e09 kg/s) volcanic plumes have been studied by using a new 3D code based on a fast Eulerian, Large Eddy Simulation model of turbulent, gas-particle volcanic plumes. The model is based on the equilibrium-Eulerian approximation [Ferry and Balachandar, 2001; Cantero et al., 2008] for a polydisperse flow. This approach describes the first order non-equilibrium dynamics (preferential concentration and fallout of the ash) of a polydisperse particle distribution and its interaction with the turbulence. Numerical results describe the disequilibrium between the ash and the gaseous part of the volcanic mixture and key phenomena like preferential concentration and plume entrainment. The influence of grid resolution and turbulence sub-grid models on the dynamics of the plume and on the air entrainment rate is discussed and a quantitative analysis of the influence of input parameters on the plume development has been carried out by analysing field's average and fluctuations. To coherently compare three-dimensional (3D) models with integral one-dimensional (1D) plume models (e.g., Morton et al., [1956]) we apply to 3D datasets the same averaging procedure used to develop 1D models. By this way, results can be coherently compared allowing calibration for the faster 1D models through the slower but more accurate 3D simulations. Results from 3D numerical simulations have been averaged over time and space in order to obtain the mass, momentum and buoyancy fluxes and the equivalent entrainment coefficient. By using this approach, it will be possible to study the influence of the particle grain size distribution on the entrainment coefficient.

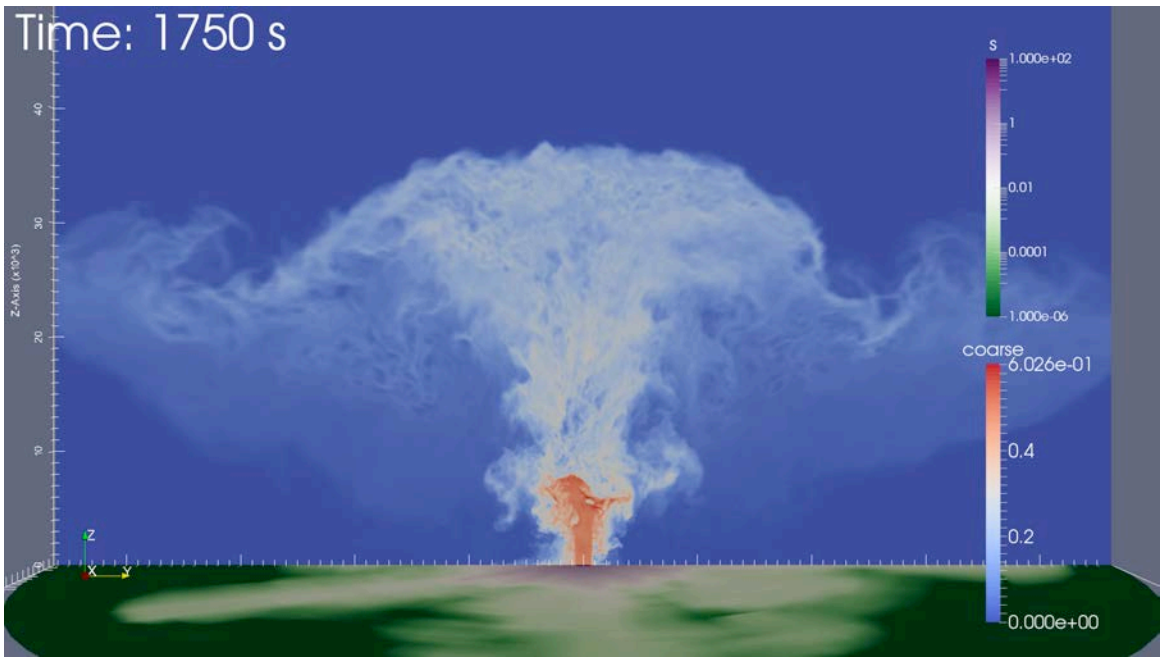

Figure 1. Vertical slice of the mass fraction of particles with diameter 0.5 mm after 1750 s of continuous ejection of steam and ash at a temperature equal to 1053 K and m.e.r 1.5e09 kg/s. The horizontal slice represents the thickness of the deposit.

Automatized near-real-time short-term Probabilistic Volcanic Hazard Assessment of tephra dispersion before and during eruptions: BET_VHst for Mt. Etna

Jacopo Selva[1], Simona Scollo[2], Alfonso Brancato[2], Antonio Costa[1], Michele Prestifilippo[2]

[1]Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Bologna, Bologna, Italy
[2]Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania - Osservatorio Etneo, Catania, Italy

Tephra dispersal may heavily affect public health and critical infrastructures, such as airports, road networks, and electric power supply systems. Mainly for this reason and because there is an increase of number of explosive eruptions at Etna, three eruptive scenarios are daily run at the Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Etneo, to forecast volcanic ash dispersal and fallout every 3 hours. However, although the results are very useful to give preliminary warnings the uncertainties are not treated. Probabilistic Volcanic Hazard Assessment (PVHA) represents the most complete scientific contribution for planning rational strategies aimed at managing and mitigating the risks posed by eruptive activity during volcanic crises and eruptions. Short-term PVHA (over time intervals in the order of hours to few days) must account for rapidly changing information coming from the monitoring system, as well as, updated wind forecasts, and they must be accomplished in near-real-time. In addition, while during unrest the primary goal is to forecast potential eruptions, during the eruptions it is also fundamental to correctly account for the real-time status of the eruption and of tephra dispersal, as well as its potential evolution in the short-term. In this work, we take into account both central and lateral eruptions that can generate short and long lasting activity respectively. For central eruptions we considered eruptive scenarios similar to the 12 January 2011, the 22 July 1998, the 5 January 1990 and 122 BC eruptions. For lateral eruptions the 2001 and 2002-03 eruptions were taken in consideration but we changed the location of the volcanic vent. Hundreds of simulations are carried out by a volcanic ash dispersal model and results are analysed by the BET_VHst model for Etna volcano. The model has its roots into present state deterministic procedure, and it deals with the large uncertainty that such procedures typically ignore, like uncertainty on the potential position of the vent and eruptive size, on the possible evolution of volcanological input during ongoing eruptions, as well as, on wind field. Uncertainty is treated by making use of Bayesian inference, alternative modelling procedures for tephra dispersal, and statistical mixing of long- and short-term analyses.

A doubly stochastic model for pyroclastic density current hazard assessment: the example of Campi Flegrei caldera

Andrea Bevilacqua[1,2], Augusto Neri[1], Tomaso Esposti Ongaro[1], Roberto Isaia[3], Willy Aspinall[4], Peter J. Baxter[5], Antonella Bertagnini[1], Marina Bisson[1], Franco Flandoli[6], Enrico Iannuzzi[3], Marco Pistolesi[7], Simone Orsucci[1,8], Mauro Rosi[9], Stefano Vitale[10]

[1]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Pisa, Pisa, Italy*
[2]*Scuola Normale Superiore, Pisa, Pisa, Italy*
[3]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Napoli - Osservatorio Vesuviano, Napoli, Italy*
[4]*University of Bristol, Bristol and Aspinall and Ass. Trisbury, United Kingdom*
[5]*University of Cambridge, Institute of Public Health, Cambridge, United Kingdom*
[6]*Università di Pisa, Dipartimento di Matematica, Pisa, Italy*
[7]*Università di Firenze, Dipartimento di Scienze della Terra, Firenze, Italy*
[8]*Università di Pisa, Dipartimento di Fisica, Pisa, Italy*
[9]*Università di Pisa, Dipartimento di Scienze della Terra, Pisa, Italy*
[10]*Università di Napoli Federico II, Dipartimento di Scienze della Terra, dell'Ambiente e delle Risorse, Napoli, Italy*

Pyroclastic density currents (PDCs) represent one of the most dangerous volcanic hazards for people living in proximity of explosive volcanoes. The zonation of areas potentially affected by this threat is therefore of paramount importance and is the first step needed to set up appropriate mitigation measures. Campi Flegrei (CF) caldera represents a high-risk volcano with a remarkable PDC hazard due to the frequent occurrence of this phenomenon in its eruptive history. Despite the fact that CF caldera has been the object of many studies in recent decades, the mapping of PDC hazard there remains particularly challenging due to the remarkable variability of potential vent locations and eruption scales, and the complex dynamics of PDC propagation over the caldera topography. In this study we have produced, through the application of a doubly stochastic model, quantitative background (also called long-term or baseline) probabilistic maps of PDC invasion able to incorporate some of the main sources of epistemic uncertainty that influence the models for aleatoric (physical) variability. The new method developed combines the spatial probability distribution of vent opening locations, the density distribution of PDC invasion areas, and a simplified PDC model able to describe the main effect of topography on flow propagation. Our results indicate that the entire caldera has the potential to be affected (with a mean probability of flow invasion higher than about 5%) and the central-eastern area of the caldera (i.e. Agnano-Astroni-Solfatara) has invasion probabilities above about 30% (with local peaks of mean probability of about 50% in Agnano). Significant mean probabilities (up to values of about 10%) are also computed in some areas outside the caldera borders. Our findings are quite robust against different assumptions about several of the main physical and numerical parameters adopted in the study. In addition to mean values of probability of PDC invasion, the study provides the estimates of the credible uncertainty ranges associated with such probabilities in relation to some key sources of epistemic uncertainty. From our analysis, uncertainty spreads on invasion probabilities inside the caldera typically range between ±15 and ±35% of the local mean value, with an average of about ±25%; wider uncertainties are found outside the caldera, with an average above ±50% and a significantly larger range of variability from place to place.

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WP6

Posters

An analysis of aleatory and epistemic uncertainties related to pyroclastic density currents at Somma-Vesuvius (Italy): insights into probabilistic volcanic hazard assessment

Pablo Tierz[1], Laura Sandri[1], Antonio Costa[1], Roberto Sulpizio[2], Lucia Zaccarelli[1], Mauro A. Di Vito[3], Warner Marzocchi[4]

[1]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Bologna, Bologna, Italy*
[2]*Dipartimento di Scienze della Terra e Geoambientali, Università degli Studi di Bari, Bari, Italy*
[3]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Napoli - Osservatorio Vesuviano, Napoli, Italy*
[4]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione Sismologia e Tettonofisica, Roma, Italy*

Long-term hazard assessment of Pyroclastic Density Currents (PDCs) still represents one of the most challenging tasks for modern volcanology. Due to their physical complexity and difficulties in observing their essential dynamics, Probabilistic Volcanic Hazard Assessment (PVHA) of PDCs is unavoidably linked to large aleatory and epistemic uncertainties. For several decades, hazard mapping techniques have mainly relied upon the spatial distribution of past PDC deposits at the specific volcanic system of interest. Single-scenario simulation strategies have also been a common practice. Only recently, comprehensive descriptions of the PDC natural variability (aleatory uncertainty) and estimations of the degree of (lack of) knowledge (epistemic uncertainty) have been formally pursued. Within this framework, field-based data is the primary key to understand possible future behaviour of the volcanic system and, hence, constrain the expected PDC phenomenology that may unfold during a given eruption. Nonetheless, in order to fully explore aleatory and epistemic uncertainties with hazard mapping purposes, an efficient combination (in terms of computational time) of PDC numerical simulator and Uncertainty Quantification Technique (UQT) is required. In this poster, we present an approach at Somma-Vesuvius (Italy) which combines Energy Cone, EC (as the PDC simulator), and Monte Carlo sampling, MC (as the UQT); and allows us to compute both aleatory and epistemic uncertainties in a feasible way. Aleatory Uncertainty (AU) is addressed through the definition of coherent Probability Density Functions (PDFs) for the EC input parameters (H0 and φ) taking into account three eruptive sizes: large, medium and small. Then AU is propagated by performing MC on the selected PDFs and running EC for each sampled H_0-φ realization.

Epistemic Uncertainty (EU) is subdivided into four different sources, namely: (1) Input Uncertainty (IU), related to boundary conditions such as different resolutions of Digital Elevation Models; (2) Parametric Uncertainty (PU), linked to the fact that the "appropriate" PDFs for H_0-φ are unknown; (3) Theoretical Uncertainty (TU), associated to possible relationships between the EC parameters; and (4) Structural Uncertainty (SU) which derives from the limitations of the simulator itself. Each type of EU is addressed in a slightly different manner.

Eventually, we can obtain Empirical Cumulative Distribution Functions (ECDFs) of the simulator outputs (basically, Area of PDC invasion, A, and Maximum Runout, MR) and, therefore, characterize all of these sources of uncertainty. In addition, a comparison among the diverse types of EU as referred to a unified measure of AU is also computed (Figure). In light of these data, they can be somehow ranked according to eruptive size and output variable considered. The results indicate that TU is the most important source of EU, independently of the eruptive size. IU tends to play a minor role except in the case of small-size MR (Figure). PU can be seen as the second most influencing source of EU. Finally, SU seems to have a limited impact on the EC outputs (Figure). Nevertheless, SU is probably the source of EU which is most arduous to properly quantify. In any case, we argue that similar procedures to the one here presented can help improve

PVHA of PDCs in a significant way. On the one hand, designing validation methodologies to be implemented on different PDC simulators can be extremely useful to puzzle out the pros and cons of each of them as well as clarify their applications and limits. On the other hand, we defend that the more comprehensive the uncertainty quantification, the richer the final PVHA product. PVHA is indeed a young branch in modern volcanology. Nonetheless, the available quantitative techniques and tools (e.g. Bayesian Event Tree, BET; Bayesian Belief Networks, BBN; Expert Elicitation methods, etc.) are being reaffirmed during recent years. As long as input data for these tools get more structured and complete, final PVHA products will consequently become more robust and defensible.

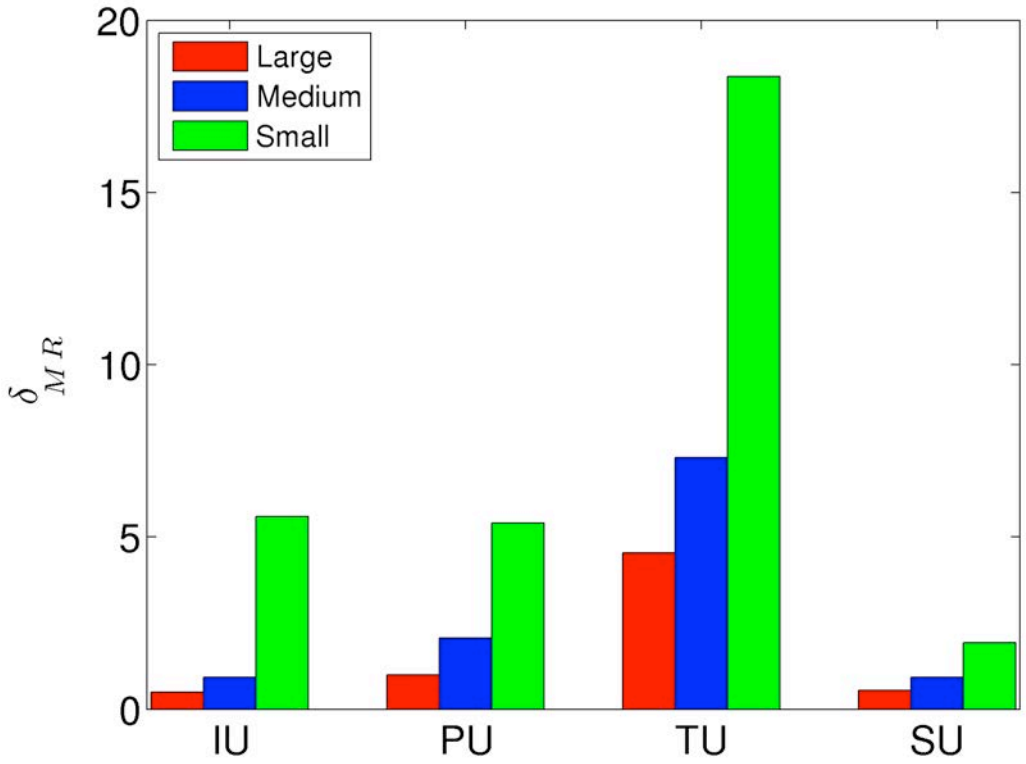

Figure 1. Comparison among diverse types of EU referred to a measure of AU, all calculated from EC runs at Somma-Vesuvius: δ_i (MR) = Δ_i / x50 (Δ_i: maximum horizontal distance between AU ECDF and alternative ECDFs (for the i-th type of EU); x50: median of AU ECDF).

An illustrative simplified application of the Cost-Benefit Analysis at Campi Flegrei

Laura Sandri[1], Pablo Tierz[1], Warner Marzocchi[2]

[1]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Bologna, Bologna, Italy*
[2]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione Sismologia e Tettonofisica, Roma, Italy*

In this poster, we follow the methodology proposed by Marzocchi and Woo (2007; 2009) for the Campi Flegrei area. In particular, we focus on the potential area invaded by Pyroclastic Density Current (PDC) in case of a volcanic crisis at this volcanic system, and try to apply the cost-benefit analysis (CBA) in order to identify a rational probability threshold to call for an evacuation. As regards the Red Area (the one to be evacuated to protect against PDCs) of the new Emergency Plan just released, we rely on one of its basic principles, that is: once the evacuation is called, all the residents in the Red Area will be evacuated. Also, in the absence of new evidence, we use the same evaluation for the model parameters R and V achieved by Marzocchi and Woo [2009] for the Neapolitan area. We also assume that individual vulnerability to PDCs is 1.

As regards PDCs invaded area (IA), we make use of the simulations performed by Tierz et al. (in prep) through Energy Cone model for PDCs in the Neapolitan area. For each potential eruptive size, we take the mean simulated IA value, and weight each of these values with the probability of PDCs generation (given the eruptive size, as in Newhall and Hoblitt, 2002) multiplied by the probability of each eruptive size (as in Orsi et al., [2009]). In this way, we obtain an expected IA given the occurrence of an eruption, accounting for every possible eruptive size, equal to 16.3 km^2. Using this value, we can compute the proportion of residents that would be killed by the PDCs if no evacuation is called and the PCD occur, which is about 22.5% of the evacuees, leading to an eruption probability threshold of about 5%. If we account for the possibility of vent opening offshore (as from Selva et al., [2010]) where no one lives, this threshold rises to 6%. By applying such thresholds retrospectively to the VUELCO simulation exercise carried out in February 2014, we see that this threshold has been overcome twice: once (slightly) between phases 1 and 2 of the exercise, and once (largely) before the release of phase 3 bulletin. However, we highlight that the VUELCO simulation covered several "future" years, in which (potentially) the scientific community would acquire new skills and understanding of the unrest processes, while the eruption forecasting performed in 2014 during the simulation only relied on the degree of knowledge available at that time.

The presented study is not meant to set a definitive threshold. Rather, its goal is to illustrate how the CBA methodology proposed by Marzocchi and Woo [2007; 2009] can be applied in practice as new probabilistic hazard assessment (e.g., [Selva et al., 2010]; [Sandri et al., 2014]; [Neri et al., 2015]) is produced and refined by the scientific community, and how such studies can contribute to rational decision making in a CBA paradigm. In this light, it is meant to show a possible practical way to bridge the gap between scientific achievement and decision making. Besides stressing this important point, we also warn that this type of analysis applies before the eruption onset, and becomes irrelevant once the eruption has started and its eruptive features (for example the vent position or the eruptive scale and character) are known. Finally, we also indicate what feasible significant improvements might upgrade the presented application of CBA.

Improving volcanic risk communication through volcanic hazard maps efficacy evaluation: Campi Flegrei Caldera case study (Italy)

Rosella Nave[1], Isaia Roberto[1], Vittorio Bosi[2], Chiara Cristiani[2]

[1]*Istututo Nazionale di Geofisica e Vulcanologia, Sezione di Napoli - Osservatorio Vesuviano, Napoli, Italy*
[2]*Dipartimento Protezione Civile, Roma, Italy*

In the communication chain between scientists and decision makers (end users), maps represent a fundamental tool and the widespread source of information on hazards zoning, and the related at risk areas definition. Anyway the relationship between volcanic phenomena, their probability and potential impact can be complex and the geospatial information not easily decoded or understood by not expert even if decision makers. Particularly, recent studies have shown that volcanic hazard and risk maps are sometime difficult to interpret and consequently preparedness to react to volcanic activity escalation and to manage the emergency may be compromised, even when users have high levels of education [Haynes et al., 2007; Moen and Ale, 1998; Newhall, 2000, Nave et al., 2010]. Focusing on volcanic hazard, the goal of MED SUV WP6 Task 3.3 is to improve the communication efficacy of scientific outputs, as maps, shaping them taking into account opinions and needs of the different stakeholders, in order to contribute in filling the gap between scientists and decision-makers.

First steps of the TASK3.3 were:
1) To define a Test Volcanic Area: the chosen area is the Campi Flegrei Red Zone as defined in National Emergency Plan for Campi Flegrei.
2) To identify the sample: sample is formed by selected decision makers and officials (End users) belonging to Civil Protection National Department Campanian Region Civil Protection to the Campi Flegrei red zone municipalities included in Campi Flegrei RED ZONE, the area exposed to pyroclastic flow hazard including: Naples (districts of Pianura-Soccavo and Bagnoli-Fuorigrotta and the neighbourhood: Posillipo, Chiaia, Vomero, Arenella), Pozzuoli, Bacoli, Monte di Procida, Quarto, Marano, Giugliano (Figure 1).

These selected end users, working in the local of Civil Protection with different roles, have already attended training courses on topics related to volcanic hazard and risk in Neapolitan area. The course were conceived out as collaboration between Civil Protection Department, INGV Osservatorio Vesuviano and Campania Region and carried two years ago.

The ongoing research is an Evaluation/Validation procedure, based on the following phases:

PHASE 1: semi-structured interviews, with the selected sample of decision makers and civil protection officials. The interviews have been designed to acquire both quantitative and qualitative data, whose analysis assess level of respondents' understanding of information as presented on the maps, and their needs in representing the complex information embedded in the volcanic hazard by using maps.

PHASE 2 According to data analysis and employing GIS techniques new geospatial representations of information related to volcanic hazard and risk will be produce. A second round of semi-structured interviews on these new maps is requested to complete the evaluation/validation procedure.

PHASE 3: development of a leaflet as "guidelines" that can support decision makers and officials in using these maps also as a communication tool in population at risk information program. The leaflet "guidelines"

will be developed according to the WP6 Task 3.1 deliverables

The findings from the WPS Task 3.3 not only aim to elucidate some difficulties in understanding the existing hazard maps but also to develop an appropriate methodology to produce maps that can maximize the information flow, increasing people preparedness both during volcanic crises and long-term unrest period.

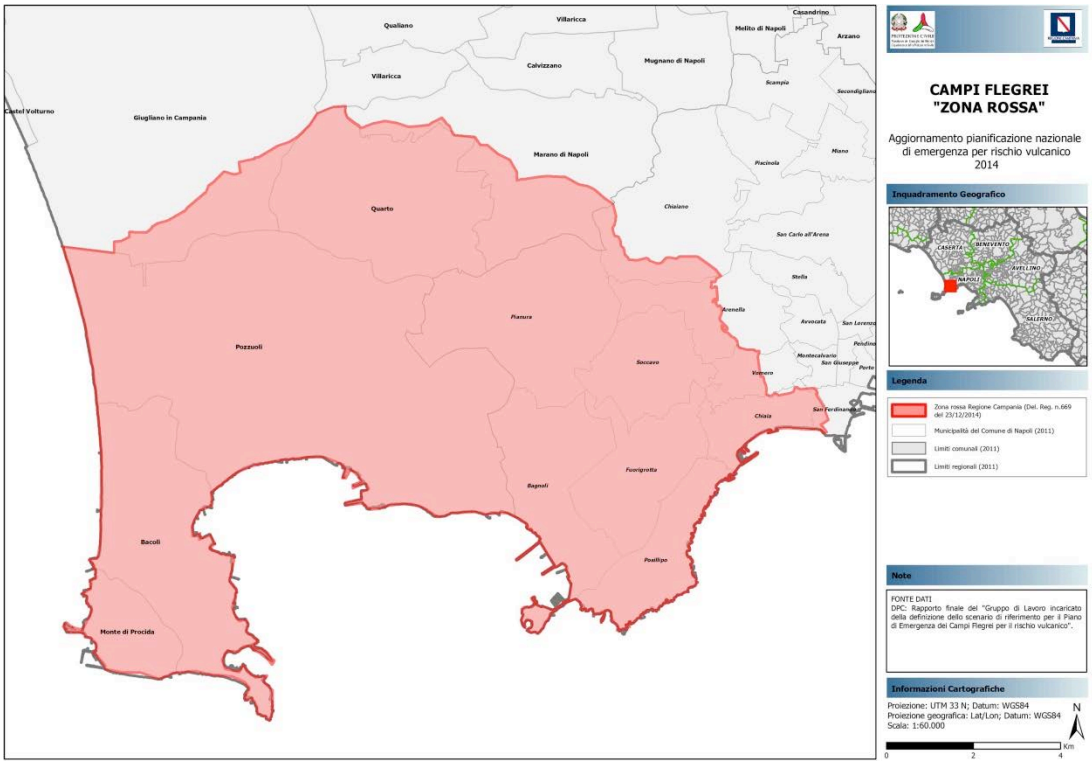

Figure 1. Campi Flegrei Red Zone showing location of the municipalities.

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WP7

Talks

Measurement campaign of a FBG strain sensor on Etna

Nicolò Beverini[1], Massimo Calamai[1], Daniele Carbone[2], Giorgio Carelli[1,3], Nicoletta Fotino[3], Francesco Francesconi[3], Salvo Gambino[2], Renzo Grassi[3], Alfio A. Messina[4], Enrico Maccioni[1], Mauro Morganti[5], Fiodor Sorrentino[3,6]

[1]Dipartimento di Fisica, Università di Pisa, Pisa, Italy
[2]Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania - Osservatorio Etneo, Catania, Italy
[3]Marwan Technology Srl, Pisa, Pisa, Italy
[4]Istituto Nazionale di Geofisica e Vulcanologia, Sezione Geomagnetismo, Aeronomia e Geofisica Ambientale, Roma, Italy
[5]Istituto Nazionale di Fisica Nucleare, sezione di Pisa, Pisa, Italy
[6]Istituto Nazionale di Fisica Nucleare, sezione di Genova, Genova, Italy

We present a field campaign of a FBG strain sensor prototype on Mt. Etna. The campaign aimed at checking the system performances in out-of-the-lab conditions and in the hostile volcanic environment (lack of mains electricity for power, strong diurnal temperature changes, strong wind, erosive ash, snow and ice during the winter time), and to determine whether measurable changes are induced across a 1989 fracture system during the paroxysmal phases of Etna's volcanic activity. We found positive correlations between the signal detected by the FBG strain meter and the volcanic tremor detected by a seismic station at Mt. Etna (ESPC). The installation has been performed on a surface trace where the signal is dominated by thermally induced strain; in the next future we plan to test an improved, tri-axial FBG strain sensor prototype to be installed underground, where the sensitivity of the device to micro tremors will increase.

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Posters

Combined AMT and ERT imaging of the Furnas caldera and Ribeira Grande hydrothermal area (Azores archipelago, Portugal)

Svetlana Byrdina[1], Jean Vandemeulebrouck[1], Volker Rath[2], Fatima Viveiros[3], Colin Hogg[2], Teresa J.L. Ferreira[3], Catarina P.P. Silva[3]

[1]ISTerre, UMR 5275, Université Savoie Mont Blanc, IRD R219, CNRS, Domaine universitaire Le Bourget du Lac, Cedex, France
[2]Dublin Institute for Advanced Studies, School of Cosmic Physics - Geophysics Section, Dublin, Ireland
[3]Centro de Vulcanologia e Avaliação de Riscos Geológicos, Universidade dos Açores, Portugal

We present first results of an electrical resistivity tomography survey combined with audio-magneto-telluric measurements at the Furnas caldera and the CO_2 leakage zone of Ribeira Grande. The purpose of the Furnas survey is to delimit the extent, the geometry, and the depth of the hydrothermal system manifested by strong diffuse degassing, as we know from previous monitoring studies [Viveros et al., 2015]. Based on the earlier results of Hoover et al. [1976] we expect this hydrothermal system to be characterized by very low resistivity (possibly less than 1 Ohm m). Joint modelling of our newly obtained, densely spaced data in the northern part of the Caldera will improve our knowledge on the subsurface geometry of the hydrothermal system in this area, and thus also contribute to the understanding of the dynamics of this volcanogenic system. A second target is a zone of CO_2 leakage occurring along a regional fault at Ribeira Grande. It has been triggered by a geothermal drilling [Viveiros et al., 2014], and therefore is quite recent. The ERT profiles crossing the fault zone reveal an image the gas-rich plume, and help to determine the currently unknown depth of the leaking layer.

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Via di Vigna Murata, 605
00143 Roma
Tel. +39 06518601 Fax +39 065041181

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