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Miscellanea INGV

MED-SUV Final Meeting

Rome 6 | 7 April 2016

31

Istituto Nazionale di
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Editors: Giuseppe Puglisi, Letizia Spampinato, Danilo Reitano

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Istituto Nazionale di
Geofisica e Vulcanologia

MEDiterranean SUpersite Volcanoes
MED-SUV

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Suomi satellite of NOAA (image source NASA)

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Preface

Next 31 May 2016 the MED-SUV project will end. Surprisingly time has run it seems yesterday when we met for the first year meeting in Nicolosi. Throughout the project life, the Consortium has carried out activities relating to the project management, scientific/technological development, and dissemination. The management has included many different aspects among which the organization of the start the project and all the consortium activity, in terms of definition of the Governance Bodies, work package meetings and intra-work package meetings, management of the project's products, and provision of the guidelines for the scientific and financial reporting. Management also aimed at finding synergies with EC and international initiatives, such as geohazard activities of GEO-GEOSS, EPOS-PP/EPOS-IP and the other two FP7 Supersite projects - MARsite and FUTUREVOLC - to build the future research infrastructures for Earth Science in Europe. WP1 has made great efforts to put together principles and rules to define, classify, and protect your data and products, in order to promote data sharing and the circulation of the information among the project partners, and outside the Consortium.

The scientific and technological activities included field campaigns for data collection at Mt. Etna, Campi Flegrei and Vesuvius and instrumentation testing, laboratory and field experiments, software, prototypes and instrumental development, design and implementation of the MED-SUV e-infrastructure, and the pilot phases carrying out. All these activities have represented the core of the project as they have involved the most part of the MED-SUV participants and have also promoted scientific collaborations with scientists external to the project and with other EU projects.

The dissemination activities have consisted in participation at international and local scientific conferences and initiatives, publication of scientific articles in peer-reviewed international journals, interviews contributing to journal articles, videos and TV programs, use of social networks for project promotion, and distribution of project material. Moreover, some educational activities were carried out in selected schools of countries involved in the project (Spain and Italy), in order to raise pupils' understanding of what a volcano is and what kind of hazards are associated with its activity.

My personal consideration is that as a whole, the MED-SUV project has achieved almost all its key objectives, thus it has provided its contribution to the FP7 Work Programme 'Cooperation' and more specifically on the activities outlined in the Call ENV 2012.6.4-2. In this sense, I believe that MED-SUV has contributed to the achievement of the objectives of promotion and help in knowledge, transfer, assessment, uptake and exploitation of scientific data and results by demonstration and delivery of innovative tools and services. The project has, in fact:

- increased the European technical know-how for monitoring hazardous volcanoes, developing new monitoring sensors to improve the accuracy, precision and quality of measurements, and new methodologies of data acquisition and processing,
- developed cutting-edge solutions in volcano monitoring by promoting the collaboration between the scientific and industrial partners of the consortium. This collaboration has resulted in the design and implementation of prototypes of cutting-edge systems/instruments for measuring new in-situ parameters, reducing the costs, increasing the accuracy of measurements, and integrating the EO and in-situ data, as well as the implementation of new methods for data analysis,
- implemented an e-infrastructure for data access and distribution compliant with the GEO/GEOSS interoperability principles and expectations. Indeed, the e-infrastructure will ease the access to observations and data, thus providing the most important and effective contribution to the GEO 2012-2015 work-plan,
- improved the use of scientific observations and related information to notify policies, decisions and actions associated with disaster prevention, preparedness and mitigation. Indeed, a robust cooperation between scientists, decision-makers and end-users is needed to protect citizens living in or near volcanic areas from volcanic threats. The results obtained can help the implementation of actions devoted to volcanic risk preparedness by exploiting scientific, social and economic resources.

So welcome to the final meeting of the MED-SUV project. The one and a half day of meeting will offer the opportunity to sum up and discuss the main project achievements that I have just shortly reported, as well as to explore and sketch possibilities to continue the scientific collaboration among the Consortium partners. The other half of the second day will be devoted to a face-to-face debate with some of the possible stakeholders of MED-SUV. The meeting schedule foresees also the last social dinner, at which I hope all of you will attend. Similarly to the previous two meetings, the special guests will be the Advisory Board Members, whose participation will certainly help us to synthetize the three years of activities, extract the key outcomes, and to evaluate future perspectives of collaboration in the European framework.

Project Leader
Giuseppe Puglisi

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WP1

Talks

Deliverable 1.5: Implementation and Results

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[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*

Among the deliverables that WP1 implemented through the project life, the deliverable 1.5 (D1.5) it is surely the most relevant since it is aimed at giving a look beyond the project; for this reason it has been the most complex and long to prepare. The document itself is made by three distinct parts, which are in strictly connected. None of these is legally binding, but in overall they give a clear direction towards the community represented in the project aims. The first part consists in a data policy proposal that starts from what assessed at the beginning of the project (D1.2) and experienced in the implementation of the MED-SUV products and e-infrastructure. The objective, declared in the DoW is that this proposal might be applicable to the other EU Supersites. EC promoted investigations of geologic hazards for the study of four Supersites: the Marmara Sea fault zone, in Turkey, the Icelandic volcanic zone, and Mt. Etna, Vesuvius/Campi Flegrei volcanoes, in Italy. In this view, indeed, MED-SUV project as whole is the ideal forum to find European enforceable data policies aimed at promoting retrieval and systematic access to the EO and the in-situ data, properly and ethically managed. The implementation of a clear data policy plays a vital step in the advancement of the Supersites knowledge and technology, and the exploitation of their Foreground. The second part is the Exploitation Agreement. This document defines and rules the project foreground and its exploitation after the end of the project, when the Consortium Agreement will not be in force anymore. The document regards the possible commercial exploitation of the implemented technological products, as well as the shared use of the scientific and technological products. The document will be finalised in agreement with the involved partners. The third part of the D1.5 is the Memorandum of Understanding, which will be agreed among the relevant partners at the end of the project. The document identifies those components of the developed monitoring systems and infrastructure to be maintained in operation in the frame of GEO.

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WP2

Talks

The new Monitoring and Observing Systems - A WP2 overview

Christian Minet[1] & WP2 Team

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The Work Package 2 (New Monitoring and Observing Systems) aimed at developing new instruments and monitoring systems to measure new parameters, increase the accuracy and precision, increment the spatial and temporal data sampling and reduce the costs for collecting all the information. A brief work package overview will show its status close to the end of the project in terms of Deliverables & Milestones, Meetings and Dissemination activity. It will also include highlights from the different Sub-Tasks. All the scientific and technical details will be presented by the different Sub-Tasks in following oral presentations and on posters. A special emphasis will lie on the cooperation that was developed between the WP2 partners.

Development and test of a tri-axial FBG strain sensor for volcano monitoring

Nicolò Beverini[1], Daniele Carbone[2], Giorgio Carelli[1,3], Francesco Francesconi[1,3], Salvo Gambino[2], Umberto Giacomelli[1], Renzo Grassi[3], Enrico Maccioni[1], Mauro Morganti[4], Fiodor Sorrentino[3]

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Advancements in opto-electronics have allowed the development of low-cost sensors, reliable, rugged and compact, thus particularly suitable for field application. Fiber Bragg Grating (FBG) sensors are nowadays an extensive tool for monitoring, diagnostics and control in civil engineering. However, very limited literature exists on geophysical applications of FBG sensors, although these devices might have a potential impact in such field. In fact stress and strain changes are among the best indicators of impending volcanic activity. In volcano geodesy, borehole volumetric strain-meters are mostly utilized. However, they are not easy to install and involve high implementation costs. FBGs are fabricated by creating a periodic variation in the refractive index of the core of an optical fibre, obtained via exposure to UV radiation. When the radiation generated by a broadband source is injected into the fiber and interacts with the grating, only the wavelength in a "narrow band" (~0.2 nm) can be back-reflected without any perturbations in the other wavelengths. The reflection wavelength is determined by the spacing between the individual grating planes, which is set during manufacture of the Bragg grating. Thus, the fiber Bragg gratings reflection wavelength can be set arbitrarily. When a load is applied to a structure, the grating is strained and this effect causes a change of the Bragg spacing. This leads to a change of the reflected wavelength and the strain measurement is then possible: an advantage of the FBG sensors is that the Bragg wavelength is a linear function of the strain. The main drawback is the temperature dependence of the output signal. In the framework of the EC FP7 MED-SUV project, we have developed strain sensors based on the fiber Bragg grating (FBG) technology. The system performances are tailored to suit the requirements of volcano monitoring, with special attention to power consumption and to the trade-off between performance and cost. In comparison with previous implementation of the FBG technology to study rock deformations, the system offers a higher resolution and accuracy in static measurements and a smooth dynamic response up to 100 Hz, implying the possibility to observe seismic waves.

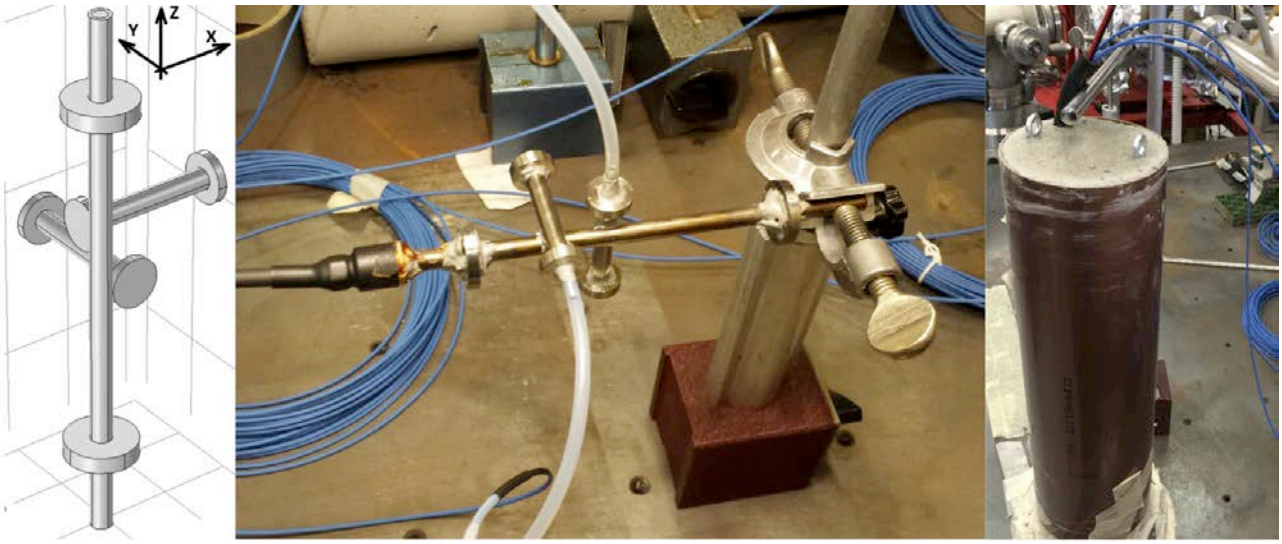

Figure 1. The multi-axial strain sensor. Left: mechanical design; centre: multi-axis prototype; right: borehole system.

Additional features are a low-cost readout system and a multi-axis strain sensor configuration. Preliminary field campaigns were carried out on Mt. Etna (Italy) using a prototypal single-axis FBG strain sensor, to check the system performances in out-of-the-lab conditions and in the harsh volcanic environment (lack of mains electricity for power, strong diurnal temperature changes, strong wind, erosive ash, snow and ice during the winter time). Results from the field campaign showed positive correlations between the signal detected by the strain meter and the volcanic tremor detected by seismic stations. In a second phase of the MED-SUV project, we developed a prototype of tri-axial strainmeter for geophysical applications (see figure) based on a new interrogation method, which pays attention to the trade-off between resolution and cost, and on a new multi-axis design suitable for on-field application in the hostile volcanic environment. This instrument is suitable for borehole installation and will be tested on Etna soon.

New Spaceborne techniques for volcanic ash plume monitoring: introducing the Plume Elevation Model (PEM) and SAR Doppler anomalies

Marcello de Michele[1], Daniel Raucoules[1], Claudia Spinetti[2], Stefano Corradini[2], Luca Merucci[2], Christian Minet[3]

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[3]*Deutsches Zentrum für Luft- und Raumfahrt, Köln, Germany*

Within the MEDSUV project BRGM WP2 team has worked on the influence of volcanic plumes on Synthetic Aperture Radar signal on TerraSAR-X data and on RADARSAT-2 data. In collaboration with DLR and INGV, we have acquired data on two test sites, Iceland and Mt. Etna. The use of SAR data to characterize volcanic plumes as a complement to other in-situ and remote sensing techniques has been explored. We used these two SAR systems to analyse Doppler anomalies occurring during the SAR image formation, potentially due to the presence of a volcanic ash plume. The source of anomalous (metric) SAR signal delay, observed in de Michele et al. [2013], has been investigated. The proposed method showed that the SAR signal is perturbed by the volcanic plume during the actual process of SAR image focusing. However, the plume signal is not the only significant signal affecting the SAR data; other components such velocities of ground features (such as river discharges, ocean currents) and potentially steep topographic morphology affect the SAR acquisition process. In parallel, we discovered a new method to use Optical Satellite Push Broom Systems and in particular Landsat 8 to extract a detailed map of the ash plume elevation. We refer to it as a Plume Elevation Model (PEM).

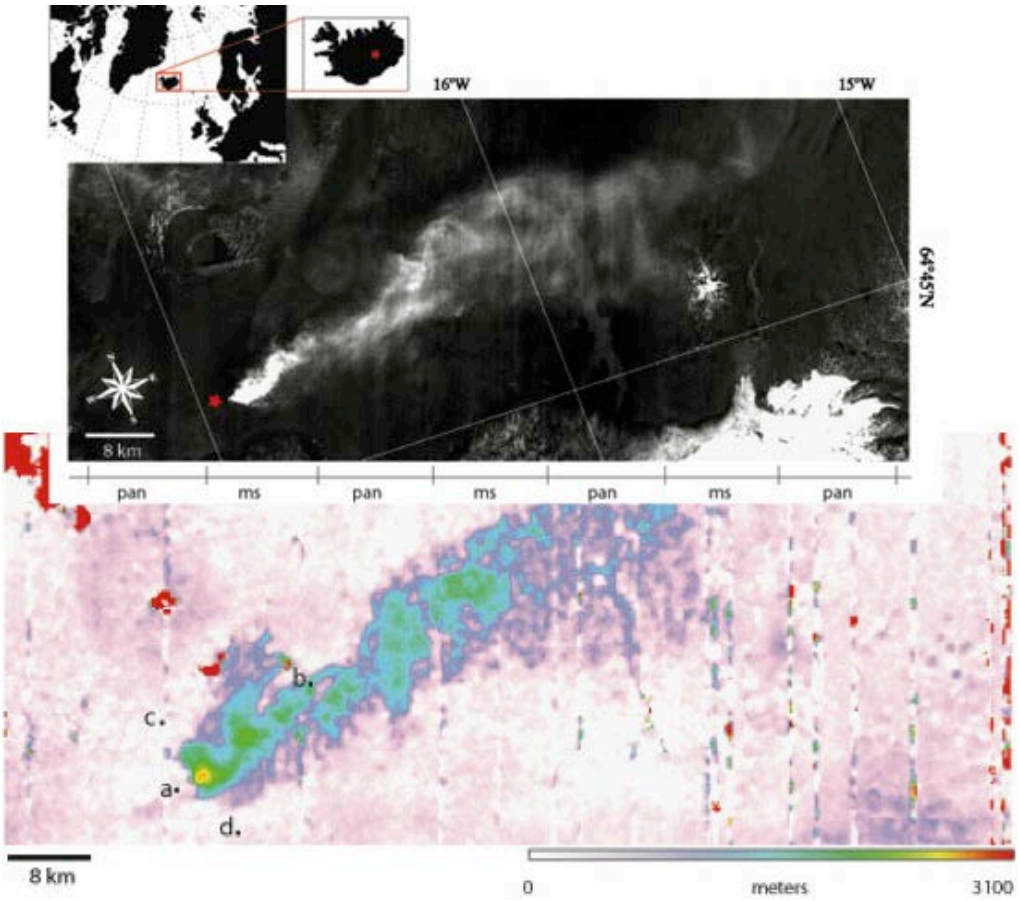

Figure 1. The volcanic Plume Elevation Model (PEM) derived from Landsat 8. Holuhraun (Iceland) 2014 fissural eruption.

We exploit the short time lag and resulting baseline that exists between the multispectral and the panchromatic bands to jointly measure the epipolar offsets and the perpendicular to the epipolar offsets. This way we were able to measure both velocity and height of the ash plume. We apply the method on Holuhraun 2014 fissure eruption (Iceland) and Mt. Etna volcano (eruptive episode on 2013). The collaboration with WP3 INGV partners allows the validation of the results obtained for the Etna test case by using independent measurements derived from both ground (VIS camera) and space-borne measurements (MODIS and SEVIRI). This method represents a new tool for volcano monitoring.

A tool for mapping the evolution of a lava field through the Etna video-surveillance camera network

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In active volcanic areas it is often difficult carry out direct surveys during an eruption, remote sensing techniques based on airborne/satellite platforms and ground-based sensors have remarkable monitoring potentialities in terms of safety and observation capability. In addition, the recent development of high resolution digital cameras, laser scanners and SAR instruments have improved the ability to obtain reliable measurements for modelling the evolution of effusive and explosive eruptions by following the rate of advancement of a lava flow or the dispersal of a volcanic plume. In order to collect data at an adequate level of accuracy and frequency it is not possible to exclusively rely on airborne or satellite methods and it is necessary to carry out measurements using also remote sensing instruments operating on the ground. Among the other techniques, the use of a simplified photogrammetric approach based a video-surveillance camera network represents a straightforward alternative for rapid mapping in active volcanic areas. Therefore a procedure for optimizing and extending the observational capability of the Etna NEtwork of Thermal and VIsible cameras (NETVIS) for systematically monitoring and quantifying surface sin-eruptive processes was implemented. The activity included also the extension of the permanent video-surveillance network by installing additional mobile stations. A dedicated tool for automatic processing of image datasets was developed and tested in both simulated and real scenarios to obtain a time series of digital orthophotos for tracking the evolution of a lava flow emplacement. The developed tool was tested by processing images acquired by the Etna_NETVIS sensors, in particular from Monte Cagliato thermal camera, during the 2011 paroxysmal episodes of the New South East Crater that poured lava flows in the Valle del Bove.

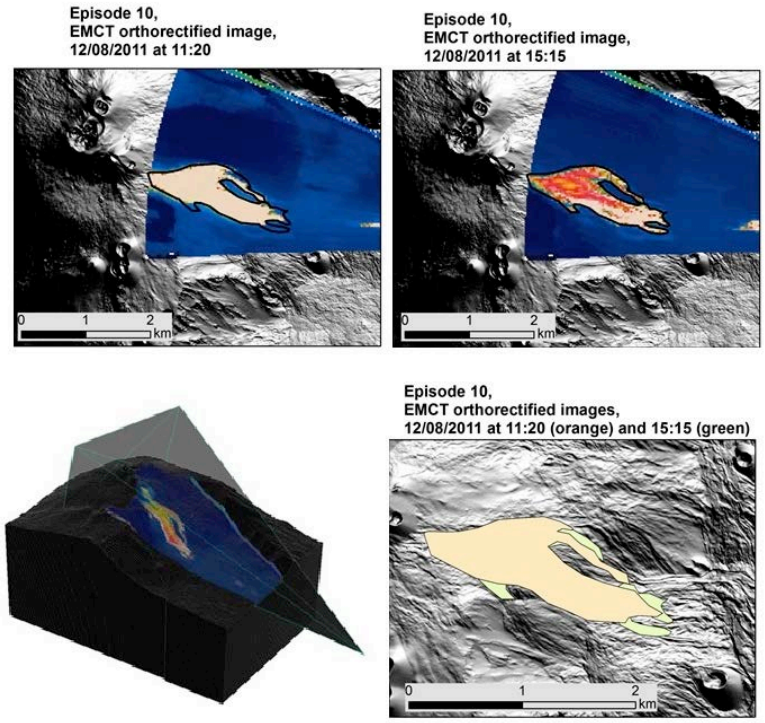

Figure 1. Digital orthophotos obtained using NETVIS tool. Thermal images acquired by the Etna_NETVIS sensor Monta Cagliato camera (episode 2011).

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WP2

Posters

Time series of lava flow extraction by the automated InSAR volcano monitoring system

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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. 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 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 task and 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. The activities of data retrieval and data preparation require a significant part of the processing time and shortening those leads to much quicker results. In the framework of remote sensing task of MED-SUV project, DLR-IMF is responsible for developing an automated SAR satellite-based system which will automate the entire time consuming tasks and allows an operational monitoring for ground deformations over active volcanoes. The automated volcano monitoring system keeps all logging updated and prepares reports showing the data processing results. Furthermore, the system will deliver specified reports and maps to a database for review and used by specialists. The interaction of the person doing the processing will be minimized and iterative processes will be totally avoided. Users should get in contact with DLR personnel and agree on a test-area, time period and acquisition geometry and once the system starts producing results, there will be an automated upload to a dedicated ftp-server to which the user will get access, including E-Mail alert. We applied the InSAR time-series analysis to TerraSAR-X data acquired on both ascending and descending orbits from December 2010 to November 2011. 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 and also extract the lava flow direction. Besides the supersites, the demonstration of the System is performed to monitor Piton de la Fournaise volcano and its historic eruptions in 2015 have been used to validate the applicability of the System.

A new datalogger and its application for seismic data recording in Solfatara geothermal field (Italy)

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We realized a new upgraded version of GILDA data logger. GILDA is a 24 bit low power digitizer devoted to geophysics data acquisition. We used GILDA for several experimental acquisition tasks with different sensors, such as Electrometers (Stromboli DPC-Paroxysm Project), MEMS accelerometers (seafloor station, CUMAS Project), Sack-Evertson dilatometers (Stromboli, Campi Flegrei and Vesuvius), geoelectric selfpotential sensors (test in Campi Flegrei for real time data acquisition), mobile seismic network for drilling sourveillance (Campi Flegrei, CFDDP; Iceland, KMDP Project). We currently use GILDA as acquisition system for the permanent seismic networks devote to monitor Vesuvius, Campi Flegrei, Ischia and Stromboli activity. Thanks to the MedSUV Project, we have been able to improve GILDA datalogger. In particular, in order to further reduce power requirement we have modified the GILDA firmware adding the management of GPS power cycling. Moreover we have simplified the data extraction from the SD micro card when the GILDA is used in standalone mode. We tested the new version of GILDA datalogger during an experiment at Campi Flegrei. We realized a multi-channel multi-parameter acquisition system, based on three datalogger for a total of 12 available channels. The system has continually transmitted data to the Observatorio Vesuviano and also acquired the data locally on SD micro card. This experiment allowed us to identify some interesting features of the seismic noise generated by hydrothermal activity of the Solfatara volcano. Another experiment is being carried out on Etna where GILDA datalogger will be used to record data from the dilatometer based on optical Fiber Bragg Grating systems (WP2, Sub-Task 2.2.2. MED-SUV Project).

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WP3

Talks

The MED-SUV Multidisciplinary Interoperability Infrastructure

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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. 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 set up an advanced e-infrastructure allowing heterogeneous data systems to provide and share their resources. Based on the approach and architecture described in the "Data Sharing, Integration and Interoperability" document, an instance of the GI-suite Brokering Framework has been deployed on INGV-OE premises. It has been configured to broker several different data sources including: DLR; INGV-Rome Iris Event; INGV-Rome Iris Station; ESA/TerraDue MEDSUV; UNAVCO Station Metadata Site; MED-SUV data repository including INGV GSAC (Geodetic Seamless Archive Centers) and a Web Service for Termocamere. The e-infrastructure has been extended to support authentication and authorization at data source level. The e-Infrastructure is accessible by MED-SUV users through the MED-SUV Web Portal. It also exposes web services interfaces to connect with external systems including GEOSS. The MED-SUV Consortium carried out a survey to collect users feedback about e-infrastructure functionalities and portal usability. The architecture and capabilities of the MED-SUV Multidisciplinary Interoperability Infrastructure will be presented and demonstrated during the final meeting of the MED-SUV project.

Analysis of Earth Observation (EO) Data Products within MED-SUV project

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In this work, we provide a short overview of the results achieved within Sub-Task 3.1 of FP7 MED-SUV project by describing the achievements on the topic "EO data products generation and distribution". First, we exploited the interferometric capability of the COSMO-SkyMed (CSK) sensors constellation (X-band) to monitor the temporal evolution of deformation phenomena affecting the volcanic complexes of Mt. Etna and Campi Flegrei Caldera. To the aim, we focused on the DInSAR approach referred to as Small BAseline Subset (SBAS). For what attains the type and characteristics of expected EO data products, the idea was to perform separate analyses on the two selected areas at regional scale (with a spatial resolution of about 30 m x 30 m), using both ascending and descending passes of the CSK sensors. We produced mean deformation velocity maps and displacement time series, covering the whole timeframe from 2009 to almost present days. Regarding the Campi Flegrei Caldera, the CSK SBAS results allowed us to analyse both the background behaviour and the last uplift events that occurred between January 2012 and June 2014. Similar analyses were conducted for Mt. Etna. In this case, we have pre-selected SAR data pairs which were likely less affected by snow cover disturbances, keeping a trade-off between having a dataset more densely populated and, at same time, less corrupted by noise. Taking into account the meteorological history recorded at the summit crater over the period of interest during summer/fall seasons, on one hand, and the maximum number of available SAR scenes, two ascending and descending sets of SAR acquisitions have been selected, and used, for retrieving surface deformation over Mt. Etna. Furthermore, the 2015 uplift event relevant to Campi Flegrei Caldera have been investigated using the classical "two-pass" DInSAR approach. The TerraSAR-X ascending differential interferogram relevant to 20.03.2015 - 31.12.2015 time spanning, show pointing out a Line Of Sight (LOS) deformation of about 3 cm on the coast-line, in a good agreement with CGPS (Continuous GPS) data, recording a vertical displacement of about 4 cm in the same time-span in RITE station, located in the area of maximum deformation. InSAR data provision in the framework of the Supersites activities has allowed getting a first set of Radarsat-2 data from the Canadian Space Agency. In particular the 18.06.2013 - 05.08.2013 InSAR pair (Radarsat-2, Fine Beam, ascending orbit) was processed and the preliminary results, show no deformation signal, as expected considering the very low time-span Moreover, the interferogram and consequently the deformation map are likely corrupted by an Atmospheric Phase Screen (APS) signal.

From December 2, 2015, volcanic activity suddenly occurred on Mt. Etna with very violent fire fountaining at central crater (namely "Voragine"), and other intense episodes during the three following days. This sudden eruption produced a rapid deflation of the volcano and was followed, from December 8, by a seismic swarm, with almost eighty earthquakes during this day, located on the uppermost segment of the Pernicana-Provenzana fault system (PFS). This seismicity was characterized by shallow foci (from few hundred meters until 1.5 km below the sea level) and main shock with 3.6 magnitude. In order to investigate and measure the dynamics controlling and accompanying the PFS activation, a dataset composed of C-Band Sentinel-1A data (available from https://scihub.copernicus.eu/) has been used for SAR Interferometry (InSAR) analysis. Some interferograms have been generated in order to define the fault geometry and motion. Moreover, essential constraints have been achieved about the PFS dynamic and its relationship with the intense volcanic activity occurred. Finally, an analysis has been devoted to describe the processes leading to 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). Test sites have been Mt Etna and Phlegraean Fields volcanoes, both belong to Italian Supersites initiative of the geohazard scientific community. 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.

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WP3

Posters

Seismic data of Mt. Etna: the contribution of in situ data to MED-SUV Project

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In the context of main objectives of the MED-SUV Projects "Work Package 3", one goal of the sub-task 3.2.4 is to provide already available in situ seismic data concerning Mt. Etna volcano. In particular, this sub-task envisages sharing data detected during the period 2005-2011. Three kinds of seismic data have been selected for sharing with MED-SUV users: i) raw continuous signals from broadband digital stations; ii) an earthquake catalogue, concerning local shocks hypocentres 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 seismic signal. Regarding the first data type, starting from the original SUDS format seismic records (each 1-min long), stored as compressed files in the INGV-OE repository, we produced files, each 1-h long, in standard SAC format. Several working phases were performed to achieve the objective: copying data from the original repository to a temporary storage, decompressing data files, extracting the records of selected seismic stations, converting data from SUDS to SAC format, and finally moving the obtained SAC files in the MED-SUV repository. Overall, about 3.5E6 SUDS files were processed, obtaining about 2E6 SAC files, that overall amount to about 2.6 TB. If needed, raw continuous signals for sharing can also be provided in standard miniSEED format. The earthquake catalogue reports parametric information (e.g. latitude, longitude, depth, magnitude) on the hypocentres of ca. 800 earthquakes. This catalogue refers to shocks with magnitude greater than or equal to 2.0 and error threshold not greater than particular 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 provided in ASCII format. Finally, RMS amplitude values of the continuous seismic signal have been calculated by an automatic tool, processing the on-line seismic signal received from remote stations. Amplitude data are calculated over 10s long time windows, in frequency bands, 1 Hz wide, between 0.5 and 15 Hz, as well as in the unfiltered continuous signal. Data format is ASCII. Appropriate metadata (such as technical specifications, geographical coordinates of sites, etc.) have also been defined for the three data types, enabling users to perform analysis and characterization of data. All data and metadata are shared with subscriber users in the MED-SUV Project portal.

The wet refractivity tomography for improving the InSAR deformation measurements on Mt. Etna

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In the frame of the EC FP7 MED-SUV project the sub-task 3.3.2 is dedicated to improve the accuracy of the ground deformation monitoring at Mt. Etna volcano (Italy). The scope of the subtask has been modelling the tropospheric delays using GPS and multispectral satellite data in order to identify the atmospheric artefacts in the SAR interferometry. Due to the orography of Mt. Etna and the space-time variability of weather conditions, the atmospheric heterogeneities affect the ground deformation measurements obtained by GPS and InSAR with values of anomalies that can reach 100 mm (equivalent of 4 C-band fringes) respect to a standard deformation. Among various effects affecting SAR interferograms, atmospheric artefacts are the most significant and the most difficult to be excluded. For these reasons the estimation of Mt. Etna atmospheric anomalies is crucial to calibrate the InSAR measurements. Data collected by the monitoring network composed by 42 GPS permanent stations spread over and around the entire volcano edifice have been processed by the GAMIT software by adopting the Vienna Mapping Functions (VMF1). Specific software has been developed in order to derive the tomographic field of the wet troposphere over Mt. Etna volcano starting from the tropospheric delays calculated by GPS in all the stations of the network. The algorithm developed has been validated by using synthetic tests. The test results confirmed the capability of the software to return the simulated anomalies faithfully. With the aim of applying the tomography algorithm to a real case, we introduce the water vapour content estimated by the MODIS instrument on board of the satellites Terra and Aqua. A comparison of GPS and MODIS derived water vapour content has been performed over the entire 2015 data sets resulting in 0.91 of correlation with a bias of about 7%. When the cloud covers permits the use of this data, its addition provides a double benefit: it improves the tomographic resolution and it adds a feedback for the GPS wet delay measurements. Finally, the tomography algorithm was applied on InSAR Sentinel-1/IW (Interferometric Wide swath) data on Mt. Etna during the 2015 year. 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. We present the results of this analysis of some 2015 test cases.

Plume height retrieval from satellite imagery using back trajectory modelling

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Satellite-based retrieval of distribution of volcanic gas in the atmosphere can be used in the investigation of volcanic processes. A preliminary step toward this goal lies in determining plume age and height through satellite data. Here we present a procedure for calculating plume height time-series using satellite imagery of SO_2 in volcanic plumes released from Mt. Etna, Italy. Focusing on paroxysmal events, we develop an inverse model based on a backward trajectory technique to retrieve 3 key quantities in the characterization of volcanic activity: the time interval during which the plume has been injected into the atmosphere at the vent position, the altitudes at which the injection takes place and the plume height as observed by a satellite at a certain moment in time. The set of data resulting from the retrieval procedure is then validated through a-doc techniques. We use calibrated video-surveillance images for assessing the plume injection height and time and SEVIRI centre of mass procedure to validate the plume altitude at the moment of satellite overpass. We compare retrieved injection heights with measurements of sin-eruptive volcanic tremor, which reflects the eruption intensity, and therefore plume height, and find good agreement between these multidisciplinary datasets.

SISTEM integration of Sentinel TOPSAR and GPS data to analyse the dynamics preceding and encompassing the 2015 December Mt. Etna eruption

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An overall and continuous inflation characterized Mt. Etna from mid-May to the end of November 2015. Suddenly, in the first days of December 2015, volcanic activity abruptly restarted at the central crater with a very strongly explosive eruption; this kind of activity continued, with a decreasing intensity, with other episodes at the same crater and then involving, in turn, all the other three summit craters of the volcano. On 8 December, when the eruptive activity was concluding, a seismic swarm affected the uppermost part of the Pernicana fault where it joins the NE-Rift. Sentinel-1A data acquired in TOPSAR mode and in ascending orbit on April 18 and on 14 December and in descending orbit on 12 April and 8 December have been processed for producing two InSAR interferograms. These interferograms have then been integrated by the SISTEM algorithm with the ground displacements measured by two GPS surveys carried out on the NE flank of the volcano at the end of April and in mid-December 2015. Results of this data integration provide a very detailed picture of the ground deformation pattern on the volcano, preceding and accompanying the vigorous eruption and the seismic swarm; besides the general inflation of the edifice cumulated during the pre-eruptive period, the displacement of the eastern unstable flank is clearly visible, not only along the Pernicana fault but also involving the other structures dissecting this sector of the volcano.

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WP4

Talks

Clues on the origin of the current accelerating deformation of Campi Flegrei caldera

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An ascending magma batch, upon decompression, selectively releases dissolved volatiles depending on their solubilities so that, while barely soluble CO_2 dominates "deep" degassing, more soluble H_2O prevails at shallow depths. This selective release of volatiles from magma implies that heat transfer to overlying hydrothermal systems exhibit non-linear pressure dependence. By applying a gas-melt degassing model, we find that there is a narrow pressure interval (CDP, critical degassing pressure) over which the total amount of separated fluid and of the associated thermal energy steeply increases by more than one order of magnitude. Evidence of critical degassing, and consequent heating of the hydrothermal system, are clear at Campi Flegrei caldera (CFc) which is currently affected by a ten years long, accelerating deformation. The CFc deformation pattern is here explained with the overlapping of two processes: short time pulses that are caused by injection of magmatic fluids into the hydrothermal system, and a longer time process of heating of the rock. The short pulses were highlighted by comparing fumarolic compositions and ground deformations. The two independent data sets show the same sequence of anomalous peaks with a delay of ~200 days of the geochemical signal with respect to the geodetic signal. This correspondence strongly supports the occurrence of episodes of magmatic fluid injection into the hydrothermal system feeding the fumaroles of Solfatara. Seismic swarms, whose frequency is increasing in the time, accompanied each of these episodes. The heating of the hydrothermal system, which parallels the long-period accelerating curve, is inferred by temperature–pressure gas geoindicators. Referring to a recent interpretation that relates variations in the fumarolic inert gas species to open system magma degassing, we infer that the heating is caused by enrichment in water of the magmatic fluids, in addition to an increment in their flux and an increased frequency of the degassing events. A physical numerical model of the injection of magmatic fluids into the hydrothermal system nicely reproduces many of the observed data including the thermal evolution independently inferred from the fumarolic composition.

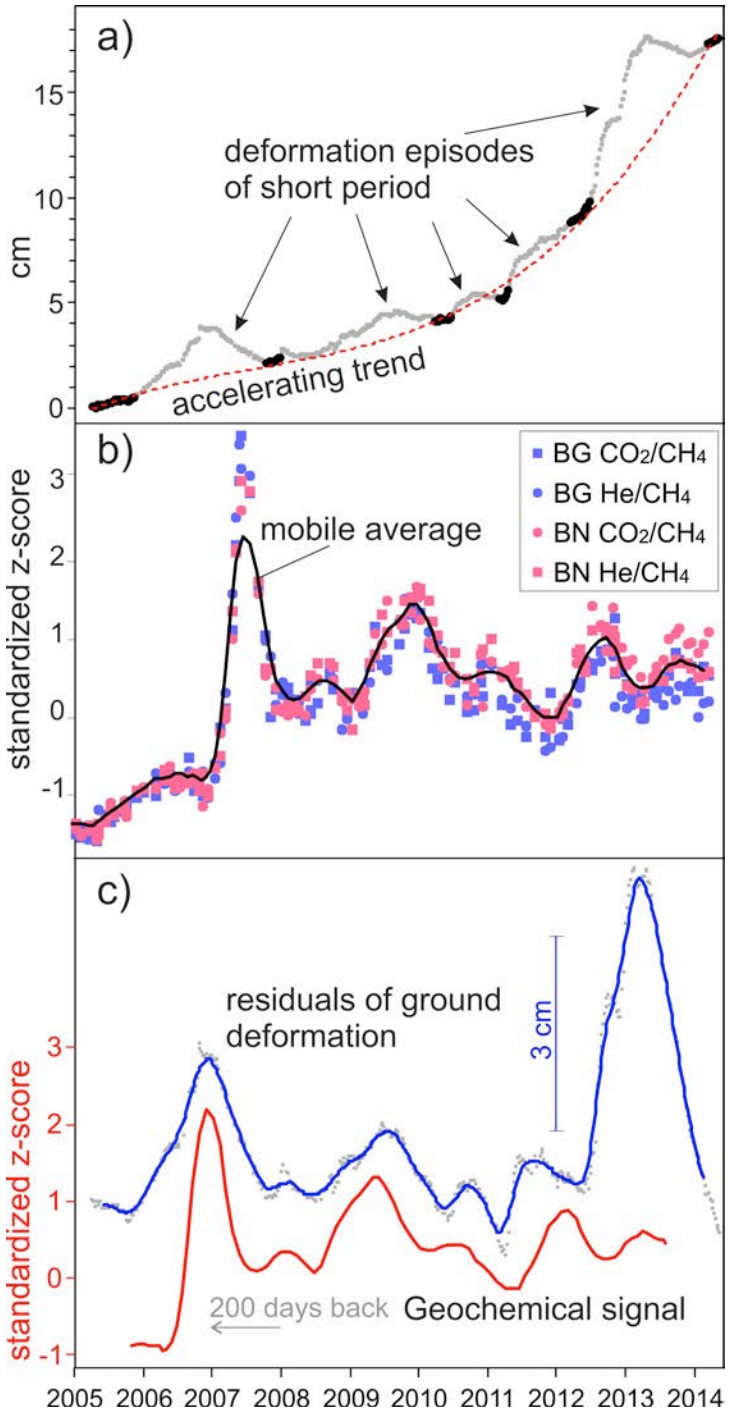

Figure 1. a) Baseline length variation between two GPS stations at Campi Flegrei; b) measured CO_2/CH_4 and He/CH_4 ratios (standardized z-score) at Solfatara fumaroles; c) comparison between ground deformation and geochemical signals.

Ground deformation signals at Campi Flegrei from borehole dilatometers and long-baseline tiltmeter data

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Since spring 2004 a small network of borehole Sacks-Evertson strainmeters, aimed to improve monitoring systems at the Italian volcanoes, has been installed around Campi Flegrei and Vesuvius. 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 analyzed 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 CO_2 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 October 2006, in correspondence of a seismic swarm of VT/LP events, in 2008, 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. Numerical simulations of shallow magma chamber replenishment at Campi Flegrei and associated ground deformation signals reveal that magma convection and mixing originate ground oscillations at a variety of frequencies. The largest energy content is in the Very Long Period (VLP) and Ultra Long Period (ULP) bands (10-4 – 10-2 Hz), corresponding to periods of some hours. The data obtained by the strainmeters and tiltmeters network at Campi Flegrei have also been analyzed in order to identify transient events in the ULP frequency range, and detect possible markers of ongoing magmatic convection and mixing. The analyses have been focused on periods of heightened caldera unrest, characterized by seismic swarms and increased hydrothermal activity. Comparative analyses of the synthetic and the monitoring data identifies a number of events in the recorded ground deformation that correlate well in terms of both waveform and frequency content. Such events have been detected in conjunction with the small-amplitude seismic swarm that hit the Campi Flegrei region in October 2006. Extending the analysis to larger datasets and further improvement of the signal matching techniques can provide an unprecedented means to identify and detect volcanic unrest from routinely monitored ground deformation signals, thus enhancing eruption forecasting capabilities. To this aim, the importance of large-band ground deformation monitoring at active volcanoes cannot be underestimated.

Hydrothermal fluid flow structures at Solfatara volcano, Somma-Vesuvius volcanic complex and Mt. Etna

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Solfatara (Campi Flegrei):

We present the first detailed 3-D Resistivity model of the Solfatara-Pisciarelli area, obtained from numerous ERT surveys during the "MED-SUV" Project. This inversion was performed by taking into account 44 000 ERT data points, as well as surface e-m resistivity measurements and the magneto-tellurics model from A. Siniscalchi et al. respectively as surface and bottom boundary conditions. The 3-D resistivity structure well matches with the CO_2 flux, temperature and self-potential variations at the crater surface. This model clearly highlights the main geological units of the area (Monte Olibano, Solfatara crypto-dome, layers of eruptive deposits), and the structures of hydrothermal fluids flow in the Solfatara crater. We particularly focus on the Fangaia liquid plume, and the feeding system of Bocca Nuova and Bocca Grande fumaroles. We also present the time-lapse resistivity variations measured on the eastern flank of Solfatara that show the dynamics of this active hydrothermal system.

Somma-Vesuvius:

Vesuvius is perhaps the volcano with the highest risk in the world threatening the 800,000 residents living on its slopes. In March 2014 an extensive field work was carried out in the framework of the "MED-SUV" Project. The aim of this survey was to identify the hydrothermal system and its fluid circulation dynamics as well as the structural boundaries associated to this volcanic complex. A high resolution deep Electrical Resistivity Tomography, 64 electrodes, 40m spacing, was performed along a NW-SE profile, 7km long, coupled with self-potential, temperature (30cm depth), and soil degassing (CO_2) with a step of 20m. ERT measurements were performed with a Wenner configuration and reached 500m depth. Inside Somma caldera, the resistivity cross-section of Vesuvius cone displays a conductive body (20-100 ohm.m) located beneath the present-day summit crater and interpreted as its hydrothermal system. This latter is also revealed by the characteristic "W" shape of self-potential signal showing with its minima a hydrothermal system of about

1,7km in diameter. The top of the hydrothermal system is at about 200-250m below the surface, except along four areas characterized by vertical rising of hydrothermal fluids up to the surface. These areas have been evidenced by temperature anomalies (increase of 6-13°C). The largest structure allowing this preferential fluid flow is the 1906s crater rim, while the two others temperature peaks are located close to the present-day fumarolic area. In the lower part of Vesuvius cone, outside of the hydrothermal system, it is possible to detect on both side of the edifice, a sub-vertical body of about 800-1000 ohm.m isolated by higher resistivity values (2500-3000 ohm.m). The more conductive body can be associated with a break in slope in the topography and also to higher CO_2 concentration. This structural boundary seems to fit with the 1631s crater rim.

Etna:

Between June and July 2015 a very deep ERT profile (Pole-Dipole configuration, 40m spacing between electrodes and a remote electrode located at ~10km from the acquisition points) has been performed in the framework of the "MED-SUV" Project. Self-potential (SP), soil gas concentrations (CO_2, ^{222}Rn, ^{220}Rn, He, H_2 and CH_4) and soil temperature (T) measurements were coupled to the ERT profile with a spacing of 20m (except for Rn: 40m). The NE-SW profile crossed Etnas summit craters in the middle of the 5720m ERT total length. Six roll along protocols of ¼ of the dispositive (600m out of 2520m tot) have been carried out and, for the first time, a high resolution DC ERT profile reached the noticeable investigation depth of 900m bgl. The results clearly evidence the central shallow hydrothermal system of Mt Etna with large positive SP anomaly, high values of T, ^{222}Rn, CO_2, He, H_2 and CH_4, in the areas where the conductive bodies reach the surface in correspondence of the summit craters and the 2014 eruptive vents (CO_2, ^{222}Rn and T). Structural boundaries, such as the Elliptic Crater (EC), were highlighted by a sharp decrease of the SP inside the EC. The high activity of ^{220}Rn (Thoron), outside the EC, highlights shallow gas source. The resistive body identified just below the NE crater is probably due to the over-heated plume rising from the top of the shallow feeding system towards the surface.

Hydrothermal activity and subsurface soil complexity: implication for outgassing processes at Solfatara crater, Campi Flegrei caldera

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The Solfatara and Pisciarelli fumaroles are the main surface manifestations of the vigorous hydrothermal activity within the Campi Flegrei caldera system. The existing fault system appears to have a major control on outgassing which in turn leads to a strong alteration of the volcanic products. Moreover the maar-nature of the crater, and its filling by more recent volcanic deposits, resulted in a complex fractured and multi-layered cap to the rising gases. As a consequence the hydrothermal alteration differently affects the rocks within the crater, including pyroclastic fallout ash beds, pyroclastic density current deposits and breccias. The changes induced in their original microstructure and in their physical and mechanical properties control the outgassing behaviour. Here, we report results from a measurement survey conducted in July 2015, and aimed to characterize the in-situ physical (temperature, humidity) and mechanical (permeability, strength, stiffness) properties. The survey also included a mapping of the surficial hydrothermal features and their distributions. Laboratory measurements (porosity, granulometry) of selected samples were additionally performed. Results show that the crater floor area comprises very different kinds of soils, from fine grained, thin laminated deposits around the two bubbling Fangaia mud pools, to crusted hummock formations along the SE and NE border of the crater. Dry and solid alunite-rich deposits are present in the western and southern part. Furthermore we observed evidences of a beginning of crust formation within the central part of the crater. A large range of surface temperatures, from boiling point to ambient temperature, were measured throughout the surveyed area. Outgassing occurs mainly along the crack system, which has also generated the crusted hummocks. Elsewhere the fluid circulation in the subsoil is favoured by the presence of coarse and highly porous sulphur-hardened levels, whereas their surfacing is hindered by compacted fine-grained, low permeability layers.

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Geodetic constraints to the source mechanism of the 2011-2013 unrest at Campi Flegrei (Italy) caldera

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Campi Flegrei (Italy) is a nested caldera and together with Vesuvius is one of the Italian GEO Geohazard Supersites (GSNL). The area is characterized by one of the highest volcanic hazard of the world, due to the very high density of inhabitants (1800/km^2), the persistent activity of the system and the explosive character of volcanism. A major unrest episode took place in 1982-84, when the town of Pozzuoli, located at the caldera centre, was uplifted by 1.80 m. Minor uplifts of few centimetres, seismic swarms and degassing episodes took place in 1989, 2000 and 2004-06. Since 2005 Campi Flegrei is uplifting, reaching a ground velocity of 9 cm/yr in 2012, showing that the caldera is in a critical state on the verge of instability. In this work, we present results from SAR Interferometry and geodetic data modelling at Campi Flegrei in the framework of the EUs FP7 MED-SUV Project. We exploit two COSMOSkyMed data sets to map the deformation field during 2011-2013. The spatial distributions of the cumulative displacement from COSMO-SkyMed ascending/descending orbits show similar behaviours, confirming the bell-shaped pattern of the deformation at least within the inner rim of the caldera. The resulting data, together with GPS data from the Neapolitan Volcanoes Continuous GPS network (NeVoCGPS) is fitted through a geophysical inversion process using finite element forward models to account for the 3D heterogeneous medium. The best fit model is a North dipping mixed-mode dislocation source lying at 5 km depth. The driving mechanism is ascribable to magma input into the source of the large 1982-1984 unrest (since similar source characteristics were inferred) that generated initial inflation followed by additional shear slip accompanying the extension of crack tips. The history and the current state of the system indicate that Campi Flegrei is able to erupt again. Constraining the deformation source may have important implications in terms of civil protection and the advanced techniques adopted provide useful information for short-term forecasting.

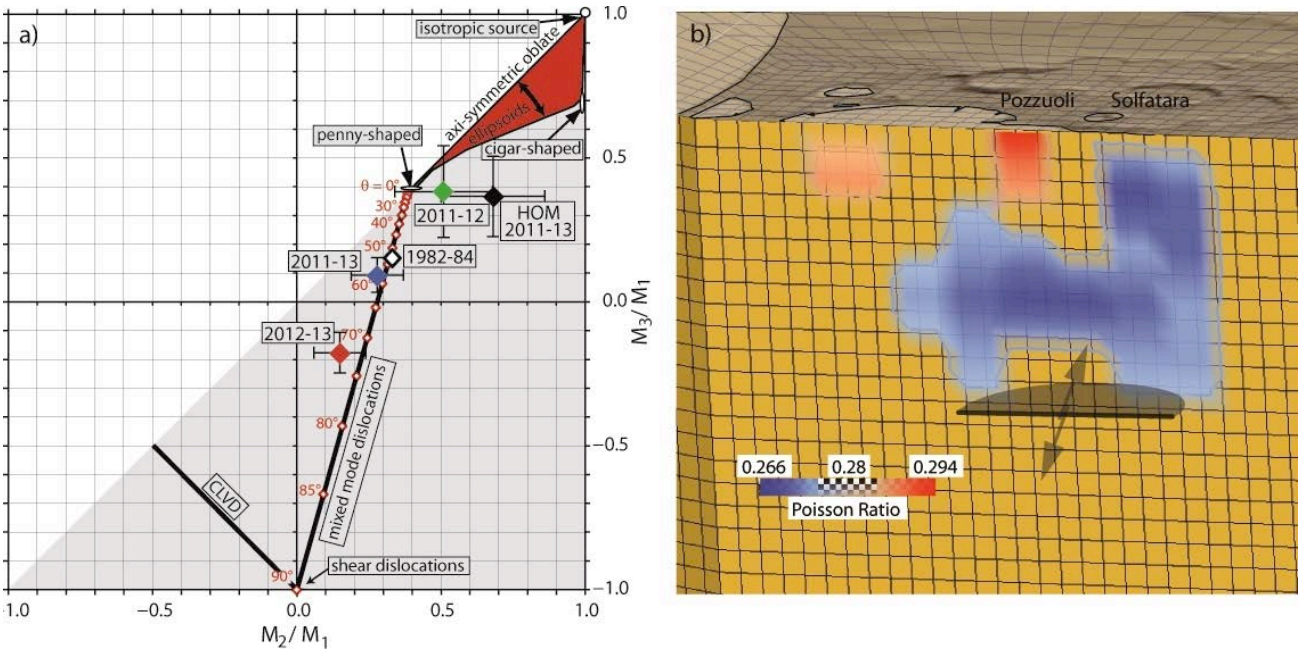

Figure 1. a) Domain of principal moment ratios and moment tensor interpretation (the diamonds are the mean model solutions). b) Sketch of the source in the FE model (E-W section through the source, view from South).

Volcanology of Phlegrean Fields: a Continuous and Fractional Wavelet analysis of tidal and tiltmetric data

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The Phlegrean Fields are an area in the west of Naples (Italy), with a huge interest in Geophysical community being a volcanic caldera among the most dangerous in the world. Reason of this is high exposure of people who live in that area (550,000 inhabitant ca.). Various techniques of monitoring exist. Among all, the control of ground deformations and variations in sea level has a considerable importance. The first one are used to verify the presence of possible traces related to a magma resurgence which could precede an eventual eruption, while the second one comes in handy to check the phenomenon of the bradyseism, which afflicts in a particular way this volcanic area. We have analysed time series of ground deformation and tidal data in this area to highlight this important geophysical features and comparing these results with those obtained from similar data in other time periods. With regard to first mentioned, we have analysed tiltmetric data. These one come from the tiltmeter network sited in Pozzuoli (that is, Pozzuoli North Tunnel and Pozzuoli South Tunnel). The second typology of data, namely tidal data, come from the tide gauge in Pozzuoli.Both time series have been analysed by means of a conventional Fourier Transform and we have obtained a Power Spectral Density (PSD) for each specific period in which we have subdivided data. But, given that data at our disposal are not stationary, it is clear that a conventional Fourier analysis is not adequate for having a complete picture of frequencies which are present in our signals. Then, another goal we want to reach is maintenance of time information, goal which is impossible to obtain with Fourier analysis. Therefore, in order to realize an advance analysis of these experimental data, we have used a wavelet approach; we have preferred choice of this kind of analysis because it allows to have information not only on frequencies but even on time. Then, it is an efficient method to obtain all the frequencies which have present in signal with a good resolution. This factor is relevant in choice of a wavelet approach. For example, the Short Time Fourier Transform is time-frequency localized, but the introduction of the window function to cover signals brings with it resolution problems. So, spectral analysis has been obtained by a wavelet approach: results are a local spectrum, for each scale in which signal has been decomposed, and a global one achieved by average on each period of local spectrum. At this proposal, we have used the Continuos Wavelet Transform and, as so-called "Wavelet Mother", we have opted for Gabor-Morlet wavelet. We have made this choice because Gabor-Morlet wavelet is a complex function modulated by a Gaussian window: this characteristic makes it extremely suitable for the Geophysical applications. But, the only use of CWT could be not sufficient to obtain a complete picture of all frequencies which are in signals. So, we have made use of Fractional Wavelet Transform, too. This for a particular reason: Continuous Wavelet Transform, which we have used, has made of components that are a sort of scaled bandpass filter in frequency domain. So, CWT results to be limited in the time-frequency plane. Then, we have analysed time series by means of Fractional Wavelet Transform proposed by Shi J. et al. [2012]. Through this FWT, we could obtain a more complete picture of all frequencies which are in signals. For each time series, we have the principal harmonic constituents: lunar semidiurnal (M2), solar semidiurnal (S2) and lunar diurnal (K1). Besides, time series show peaks for some frequencies higher than 1/hour. These peaks highlight the presence of seiches, which are standing waves occurring in total or partial enclosed body water, as Gulf of Naples is. Studies about occurrence of these seiches are very important in volcanic areas, because these oscillations could be link up with generation of discrete plumes of rising magma. Frequencies at which we notice these seiches are in agreement with previous studies. In this case, spectra obtained by means of FWT individuate variations in variance which are similar to which obtained by means CWT. These two kinds of variation underline the presence of principal harmonic constituents and of seiches, respectively. Since Wavelet analysis preserve time information about happening of these frequencies, we can obtain time periods where seiches recur in an evident way. So, we perform another kind of wavelet analysis and particularly we perform fractional derivative of CWT according to Caputos approach. We notice that spectra obtained from this kind of analysis underline presence of seiches which we are not present in "traditional" CWT and FWT analysis. For the future, we would perform this kind of analysis for other time series (not necessarily Phlegrean Fields time series) to verify if results of it have a physical meaning or are only a mathematical effect.

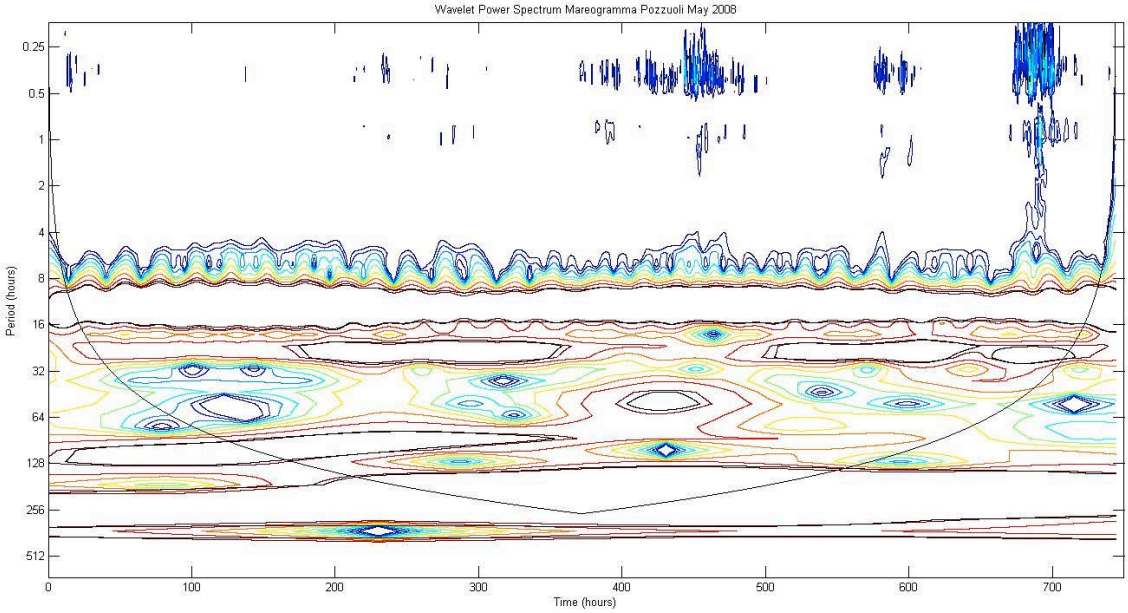

Figure 1. Local Continuous Wavelet Spectrum of Pozzuoli Bays tidal data relating to May 2008 and recorded by tide gauge in Pozzuoli.

Periodic surveys with a Multigas-type station

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Since the beginning of the MED-SUV project we have performed several acquisition campaigns, with the aim of quantifying the gas fluxes and analyse the gas species, from the main plums that characterize the Solfatara crater and the Pisciarelli site. These very active and dangerous volcanic areas are characterized by intense, diffuse degassing and fumarolic activity and are considered the most active sector of the Campi Flegrei caldera. In this context, the evaluation of magma-degassing processes and the definition of the hydrothermal processes are crucial to give a fruitful contribution to the volcanic hazard assessment of the Neapolitan district. Measurements were performed by means of a portable Multigas-type station (MultiGAS), developed at the Istituto Nazionale di Geofisica e Vulcanologia Sezione di Palermo, able to measure the concentrations of major volcanic gas species as CO_2, SO_2, H_2S, H_2, H_2O. This method described in [Aiuppa et al., 2013] involves a sequences of transects on a cross section of the analysed plume, orthogonal to the plume transport direction. During each measurement, the plume gas is steadily pumped into the sensors housing and a data-logger board capture the output signals from the sensors at a rate of 0.5 Hz. The inlet tube of the Multigas is generally kept 50 cm from the ground to capture plume gas while avoiding any soil contribution. Simultaneously to the MultiGAS measurements, a video camera pointing toward the vent, acquires image sequences of the gas plume at 25–100 frames/s. These images are then processed to calculate the plume transport speed. When processing gas fluxes data, we have noticed that wind is the main factor controlling data spread, so concurrently, we are testing an alternative way to measure the plume speed by using an anemometer, to obtain discrete speed measurements, one for each point measured with the Multigas station. Moreover, new $\delta^{34}S$ isotopic measurements have been carried out on samples collected from the Bocca Grande fumarole in the Solfatara crater, to investigate possible sulphur source changes during the 2008-2014 period, which was characterised by clear signs of a new unrest at Campi Flegrei. We have selected n. 21 samples, prepared through oxidation and acidification and analysed at the NERC Isotope Geosciences Laboratory, British Geological Survey. Measured $\delta^{34}S$ data range between +0.8‰ and +0.1‰ with a mean value of +0.33‰ and a standard deviation <0.2‰. Comparing our data with the ones available in the literature, we appreciate an increase in the new $\delta^{34}S$ 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, in particular, the sulphur isotopic signature will be used to provide information to discriminate mantle, crustal, and hydrothermal contributions (and their relative variations) to the discharged fumarolic fluids.

Artificial drawdown and natural refill experiments to estimate permeability at Solfatara, Italy

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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 are being continuously monitored at fumaroles, mudpools, hot springs, and geothermal wells. Waterlevel and temperature are being recorded at 8 sites across Solfatara along a profile aligned between Agnano Termal in the East and Fangaia in the West. Autonomous devices are used to record the water level and water temperature at 10 minute intervals. Additionally, short-term experiments at 100 Hz sampling rate have been performed with pressure sensors and seismic digitizers. At Fangaia mudpool water level and water temperature are dominantly controlled by rain water. Thus, the pool is refilled episodically. Contrary, the water level at a well producing hot water (82°C) for the Pisciarelli tennis club drops and recovers at nearly regular intervals. The induced water level changes are of the order of 1-2m and 3-4m in case of the mudpool and the hot-water-well, respectively. At first glance, both monitoring sites might seem to be fully useless to access natural changes in the Campi Flegrei fluid system. At a second thought, both time series provide a unique opportunity to monitor potential permeability changes in the aquifer system. A similar approach had been proposed to deduce earthquake-related permeability changes from Earth tide variations. Contrary to the indirect Earth tide approach, we have the chance to estimate the hydraulic aquifer properties from our monitoring data directly, since each time series contains a sequence of discrete hydraulic tests - namely drawdown/recovery tests in case of Pisciarelli and refill experiments in case of Fangaia. Although our approach is really crude (based on Cooper-Jacob), we obtained reasonable permeability estimates for both sites. Preliminary results are presented.

Geofluids interplay inferred from resistivity structure associated with earthquake hypocentres beneath the eastern side of the Campi Flegrei caldera

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An audiomagnetotellurics-magnetotelluric (AMT-MT) survey in the frequency band 0.1-100kHz 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 alignment that crosses the main fumarole emissions (Solfatara, Pisciarelli and Agnano). Such alignment is almost consistent to cross perpendicularly the main strike estimated by tensor analysis (N30°W). Impedance decomposition and rotation to such strike was applied to each sounding to define the data set for 2D regularized inversion. The resistivity model (figure) images, up to 3 km of depth, the hydrothermal and geothermal system acting above this area from which occurs the main thermal energy release of the whole Campi Flegrei caldera. We analyse the model also considering: - the seismicity of the period 2005-2015 at a maximum distance of 500 m far from the profile; - the piezometric level - the CF23 well that is located close to our profile. In the western side of the profile, the two areas of Solfatara and Pisciarelli appear clearly correlated to the same reservoir and convective processes can be invoked. A resistive structural high seems to separate these areas from the eastern Agnano crater where conduction mechanism of heat seems more likely to prevail. Model description and interpretation A The 2D resistivity model is characterized by a quite narrow resistivity range that well matches typical range of enhanced geothermal system as largely documented in the international literature. Very low resistivity values (even < 2 ohm·m) are confined in the first 500 m of depth and in correspondence of the main volcanic centres. In this depth range, underneath the Solfatara, Pisciarelli and Agnano systems the shallow and small conductive anomalies (from field level up to sea level) are detached from the deeper and bulky conductive anomalies (from a few tens of meters b.s.l. to about 300 m b.s.l.) by thin less conductive layers. It is possible to appreciate in the figure that it is just in correspondence of the piezometric level. In the Solfatara area (from 100 to -50m a.s.l.), our resistivity image amazingly overlap with the one recovered by DC geoelectrical profiling made by another RU of MED-SUV project. Due to its higher and shallower resolution, the DC model better distinguish resistivity variation around the fumaroles. On the other hand, our MT resistivity modelling thanks to a wider and deeper investigation-scale firstly reveals a clear connection between Solfatara and Pisciarelli conductive network. Below these two systems, the wide conductive anomaly is interpreted as the classical geothermal clay cap; three main interruptions (less conductive) appear within this anomaly. Two of them are located just above the main hydrothermal vents in the eastern side of Solfatara and in correspondence of the vents area in Pisciarelli: we interpret the gap in the clay cap as due to fracture within which pressurized gas escapes from the reservoir. The third interruption in the conductive zone appears to be connected to the outflow meteoric path because of it resembles a generalized geothermal system in a steep terrain. This path brings fresh meteoric water in depth below the Pisciarelli area. A resistive border, the residual of Agnano-Monte Spina crater, separates the Solfatara-Pisciarelli area from the Agnano crater sensu strictu. Here, the model clearly depicts in depth the collapsed area that originated the Agnano Lake now filled with sediments. Towards the north-eastern edge of the model, higher resistivity values (>100 Ohm.m) characterize the Soccavo hills. In the deeper part of the model, two main features deserve particular mention: the resistive plume below the Solfatara and the adjoining relative conductive unit where most of the recent (from 2005 to 2015) micro-earthquake hypocentres are confined in the same depth range of a deep hot aquifer recovered in the CF23 well. As regard the first one it well matches the reservoir of a geothermal system where temperatures as high as at least 220° make the gaseous phases prevalent. Since temperatures can be estimated in the resistive plume higher than 240°, a vapour dominated reservoir is claimed. As concern the second one, likewise a time-lapse magnetotelluric experiment during fluid injection in an enhanced geothermal system fluid that recovered microearthquake and enhanced conductivity just in correspondence of pathways of fluids migration (along an existing fault system), the area lying above Pisciarelli in the depth range 2-3 km may be associated with fluid

propagation in widespread pores and cracks. Because abnormal flows of CO_2 correspond to the geothermal reservoir, here the permeability is maintained by seismicity. High seismicity might be due to local stress accumulation near the fluid reservoir.

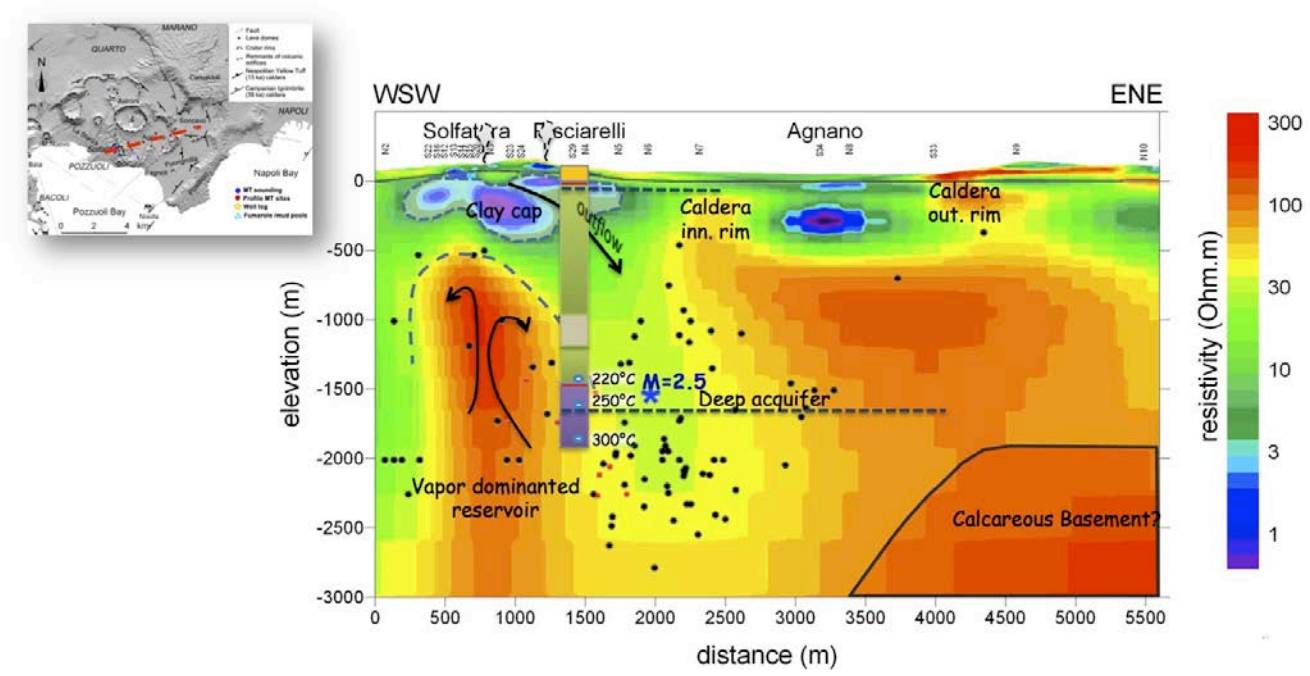

Figure 1. Resistivity model along the profile (see location map); overlaid on the model: CF23; piezometric level (continuous line); aquifers found in CF23 (dashed lines); seismicity 2005-2015 (black dots); seismicity of 10 October 2015 (red dots and blue star).

Processing of massive seismic datasets at Campi Flegrei (Italy) through Convolutive Independent Component Analysis

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A novel procedure is proposed in order to analyse continuous seismic signal on hourly scale to have a prompt discrimination among the different sources. The case study regards the Campi Flegrei caldera during the year 2006 when a swarm of volcano-tectonic earthquakes occurred. The necessity to analyse a massive data set has required applying a robust methodology and the introduction of suitable parameters to be monitored over the time. Specifically we apply the Convolutive Independent Component Analysis to the seismic recording at four broadband stations. As a result, we obtain a clear separation among meteo-marine, anthropogenic noise, hydrothermal tremor in absence of volcano-tectonic activity, whereas in non-stationary conditions a contribution connected to the corner frequency of the earthquakes emerges. We introduce a coarse-grained variable to be monitored continuously, i.e. the frequency associated with the maximum amplitude of the power spectral density of the deconvolutive independent components. This parameter is sensitive to the variation in the frequency bands of interest (e.g. that corresponding to the corner frequencies of volcano-tectonic events) and can be used as marker of the insurgence of seismic activity. We propose the following procedure to be applied routinely in the observatory practice: namely, estimate CICs on hourly series; then represent the distribution of the FMPSDA. Significative variations in the frequency bands of interest can be indicative of the insurgence of a renewed activity (e.g. VTs). Once individuated the "hot" periods, then one can go deeper with finer distinctions at a single event scale by using a simple STA/LTA (Short Time Average vs. Long Time Average) technique in order to detect events. This coarse-grained procedure on massive data through CICA would provide fast alert on the occurrence of even very-small VTs and FMPSDA may represent a suitable "observable" to monitor in the observatory practice. Finally, this approach can be employed for the prompt detection in massive data of other kinds of seismic signals such as LP, tremor, fluid-induced seismicity buried in noisy environments.

A unified finite element Fluid Structure Interaction model and code for understanding of magma and rock mechanics

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Subsurface magmatic processes and their effects on the Earths surface are an issue that requires advanced models to be unravelled. A Finite Element (FE) Fluid Structure Interaction (FSI) code is being designed in order to acquire knowledge on the processes of magma mixing in subsurface systems, to compute the response of surrounding rocks, and the synthetic geophysical signals that reveal such underground movement of magma. The FE method allows treating the intrinsic computational complexities of magma flow and rock deformation. A fully coupling between magma motion and country rocks is required for a more realistic computation of Earths signals. A segregated algorithm is used to solve the FSI problem, where the fluid and structure domains are interconnected by a standard sequence of transfer of boundary conditions. The fluid dynamics is obtained from the solution of the mass conservation of a multicomponent multiphase homogeneous mixture, and the momentum and energy equations of the mixture. Magma properties are computed as a function of the local P-T-X conditions with the most advanced laws available in literature. The full flow regime from compressible to incompressible is spanned by changing unknowns from the conservative to the pressure primitive variables. Transport equations are written in weak compact form and discretized on unstructured grids with the advanced time discontinuous formulation called deforming-spatial-domain/stabilized space–time (DSD/SST). The DSD/SST is superior in its stability, robustness and accuracy. Differently from standard FEM, space and time are dealt with in a unified way allowing an implicit consistent treatment of mesh motion due to the FSI. The least squares and the discontinuity capturing stabilizing terms prevent the spurious oscillations. Time marching algorithm is of Newton-Raphson predictor-multicorrector type. The structural model is based on the FEM Lagrangian viscoelastodynamic standard linear solid model formulation. The rate of straining or stressing affects the time-dependent response of viscoelastic a material which keeps record of the response history and possesses a memory, included in the constitutive relationship between the stress and strain tensors. The integral of the stress relaxation is splitted in time function in response to successive stress increments into elastic and viscous contributions. Adopting the standard FEM procedure the time derivative is separated and discretized giving a recursive formula for internal stress variables. The corresponding variations in the viscoelastic response are expressed in the weak integral, and linearised through the Newton method. The linearized equations are are solved with a Newmark time marching algorithm. The fluid mesh deformation is computed with the Jacobian stiffened elastostatic deformation. The code is under development. The fluid solution has been tested on standard benchmarks. The fluid mesh deformation has been validated and verified on several test cases. Various free surface fluid flows and moving object test cases has been performed to validate and verify the developed model for fluid plus mesh deformation. Preliminary results for the natural convection in magmatic systems under different external solicitation have been obtained.

High-resolution 3-D electrical resistivity tomography of Solfatara crater (Phlegrean Fields, Italy). Insights into the hydrothermal system

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Solfatara is the main degassing area of the Phlegrean Fields caldera located at the western part of Naples. This volcano shows since ten years a remarkable unrest characterized by an increase of CO_2 total flux from 1500 up to 3000 t/day, associated with large ground uplift. In order to image the structure of the shallow hydrothermal system, we performed an extended electrical DC resistivity survey at Solfatara, with about 90 resistivity profiles for a total length of 21 km. In addition we performed CO_2 flux measurements, soil temperature and Infrared thermography over the area in order to delineate active structures. The 3D-resistivity inversion has been realized with ~44 000 resistivity data points, using E4D code. At a large scale, results clearly delineate two contrasted structures: (i) A very conductive body (with resistivity below 5 Ohm.m) located beneath the Fangaia mud pools, and likely associated to a mineralized liquid rich plume, (ii) an elongated more resistive body (30 Ohm.m) connected to the main fumarolic area and interpreted as the gas reservoir feeding the fumaroles, (iii) a large resistive body (>50 Ohm.m) located beneath the Monte Olibano related to the altered lava dome. At a smaller scale, our resistivity model originally highlights the 3-D anatomy of a fumarole and the interactions between condensate layers and gas chimneys. This high-resolution image of the shallow hydrothermal structure constitutes a major step towards the comprehension of how hydrothermal systems work.

Multidisciplinary investigation (ERT, CO_2, SP and T) reveals fluid circulation at Somma-Vesuvius

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Somma-Vesuvius volcano, located near the city of Naples, threatens about 800,000 peoples producing one of the highest volcanic risks in the world. In the framework of "MED-SUV" project a multidisciplinary investigation was performed in March 2014. This survey aimed (1) at locating the present-day hydrothermal system of Somma-Vesuvius and (2) at identifying the preferential paths and fluid flows inside the volcano. The prospecting methods used were Electrical Resistivity Tomography (ABEM SAS 4000) with 64 electrodes at 40 m spacing (in Wenner alpha configuration), self-potential (SP), temperature (30 cm depth) and CO_2 concentration in the soil at 20 m spacing. All the measurements were performed along a 7 km long profile completed with roll-along (North- West to South-East). The depth of investigation for ERT reached about 500 m. This method revealed an electrical conductive body (20-100 ohm.m) centred beneath the summit of the Vesuvius cone. This conductive body was interpreted as the present-day hydrothermal system of the volcanic complex. Regarding the shape of this structure we noticed a deeply different shape respect to the one observed on both Stromboli and Vulcano volcanoes. Indeed, the Vesuvius hydrothermal system appears to act as a body which is constrained up to 200-250 m below the surface and, moreover, also emphasized by the W-like shape of the SP signal. From ERT and SP results a diameter of around 1.7 km at the maximum depth of investigation is estimated for the hydrothermal system of Somma-Vesuvius. In addition, four weak thermal anomalies (6-13 °C) are identified on the summit area. They can be explained as preferential paths of up-flowing fluids. It follows that the largest structure seen on both temperature signal and ERT tomography is related to the crater rim of the 1906 eruption. Furthermore, on both lower sides of Vesuvius cone a conductive body (300-600 ohm.m) is identified within a resistive environment (2300-2500 ohm.m). In agreement with the literature, these structural boundaries are interpreted as the 1631s caldera rim. These observations are also validated by topographic breaks in slope and higher CO_2 concentration values.

The summit part of Mount Etna revealed by High Resolution DC Electrical Resistivity Tomography coupled with complementary geophysical and soil gas techniques

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Between 25 June and 13 July 2015 a very deep ERT profile (Pole-Dipole configuration, 40m spacing between electrodes and a remote electrode located at ~10km from the acquisition points) has been performed in the framework of the "MED-SUV" Project. Self-potential, soil gas concentrations (CO_2, ^{222}Rn, ^{220}Rn, He, H_2 and CH_4) and soil temperature measurements were coupled to the ERT profile with a spacing of 20m (except for Rn: 40m). The NE-SW profile crossed Etnas summit craters in the middle of the 5720m ERT total length. Six roll along protocols of ¼ of the dispositive (600m out of 2520m tot) have been carried out and, for the first time, a high resolution DC ERT profile reached the noticeable investigation depth of 900m b.g.l.. The results clearly evidence the central shallow hydrothermal system of Mt. Etna with large positive self-potential anomaly, high values of temperature, ^{222}Rn, CO_2, He, H_2 and CH_4, in the areas where the conductive bodies reach the surface in correspondence of the summit craters and the 2014 eruptive vents (CO_2, ^{222}Rn and temperature). Structural boundaries, such as the Elliptic Crater, were highlighted by a sharp decrease of the self-potential inside the Elliptic Crater. The high activity of ^{220}Rn (Thoron) outside the Elliptic Crater highlights shallow gas source. The resistive body identified just below the NE crater is probably due to the over-heated plume rising from the top of the shallow feeding system towards the surface.

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WP5

Talks

Chemical heterogeneity of Mt. Etna magmas in the last 15 ka. Inferences on their mantle sources

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Primitive basaltic magmas are crucial in the study of the geochemical heterogeneity documented in Etna magmas and their inferred mantle sources. We undertook a systematic sampling of the less evolved basalts (Mg >50) erupted over last 15 ka, a time period which corresponds to the activity of the youngest volcanic edifice of Mt. Etna complex, i.e. Mongibello volcano. We focused on lava flows and pyroclastites emplaced during deep-dyke fed (DDF) eruptions which were driven by the rapid ascent of deeply-rooted magma intrusions that bypassed the shallow plumbing system of the volcano. All the samples were analyzed by the same laboratory to avoid analytical bias, to build a comprehensive dataset on their major and trace element compositions and to propose a coherent framework for interpreting the geochemical fingerprints of present-day Etna basalts. Trace element modelling, together with literature data for Sr isotopes, gave insight into long-term magmatic processes related to different melting degrees of the heterogeneous mantle beneath Mt Etna. DDF magma batches provide good snapshots of their mantle source heterogeneities that point to the variable involvement of clinopyroxenitic lithology, Rb-^{87}Sr-Cl-rich fluid component(s) possibly controlled by their source mineralogy, and slab-derived fluids selectively enriched in alkalis (Rb, K). The ongoing alkali (Rb, K) enrichment of the present-day magmas, well manifest since the 1970s, is decoupled from that of Sr and Cl. We propose that this process is linked to mantle source composition and is concomitant with changes in both volcanological and seismotectonic patterns of the volcano. There is no time evolution of DDF magma chemistry.

Multi-parametric investigation on the mechanism of multi-vent Strombolian activity

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In the framework of MED-SUV project, we conducted a multi-parametric experiment to acquire coupled geophysical and volcanological data on basaltic explosive activity. The experiment focused on the Strombolian activity that took place along an eruptive fissure which opened along the eastern flank of Mt. Etna in July 2014. Temporary instruments (2 broadband seismometers, 3 microphones, a high-speed video camera and a thermal-camera) were deployed near the active vents during 15-16 July 2014 and were integrated with the data recorded by the permanent networks. Several kinds of studies were performed, including frequency analysis by Fourier Transform and Short Time Fourier Transform to evaluate the spectral content of both seismic and acoustic signals; partitioning of seismic and acoustic energies, whose time variations reflects changes in the volcanic dynamics; investigation on the intertimes between explosions to investigate their recurrence behaviour; classification of the waveforms of infrasound events. Furthermore, joint analysis of video signals and seismic-acoustic wavefields outlined relationships between pyroclasts ejection velocity, total erupted mass, peak explosion pressure, and air-ground motion coupling. This multi-parametric approach allowed distinguishing and characterizing individually the behaviour of the two vents active along the eruptive fissure via their thermal, visible and infrasonic signatures and shed light in the eruptive dynamics.

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WP5

Posters

Investigation of Etnean mantle source by a geochemical study of trace elements, noble gases and Sr-Nd isotopes of some primitive lava

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In order to investigate the geochemical signature of the mantle source beneath the Mt Etna, we carried out a study focused on some primitive lava erupted from the Sicilian volcano in the last 15ky. Elemental and isotopic content of helium and argon was investigated in the fluid inclusions (FI) from olivines and pyroxenes of selected products, whereas the bulk rocks were studied with regard to trace elements and Sr-Nd isotopes content. The presence of a mantle source common to all the investigated products and characterized by a peridotitic matrix veined by about 10% pyroxenitic veins was evidenced by the geochemical study of noble gas and trace elements. A different melting degree of this common mantle source generated the studied lavas, implying a variable range of trace elements (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). The inverse relationship existing between elemental content of Sr, Ba and the $^{86}Sr/^{87}Sr$ ratio was due to the combined effect of partial mantle melting and contamination by crustal fluids. Also, this latter process is resulted responsible for the geochemical decoupling between the Sr and He isotopes. Noble gas analysis used for the above interpretation and modelling were achieved by state-of-art techniques of bulk extraction of gases from FI entrapped in a selected amount of olivines and pyroxenes (about 1-.2 g) of the studied rocks. If the investigated fluid inclusions have been entrapped simultaneously into olivine and pyroxene grains or have been captured in a different time during the magma depressurization is really unknown. In order to improve our knowledge on the conditions of entrapment for sub-ensembles of FI and to identify paths of magma depressurization by noble gas geochemistry, we attempted to perform measurements of He and Ar in single fluid inclusions by Laser Ablation-Mass Spectrometry (LA-MS) technique. The main difficulties related to these measures are represented by the very low gas content to be analysed. In order to develop a suitable method of analyses, we performed some preliminary tests on experimental glasses (basalts and rhyolites, 2 kbar of pressure) bearing H_2O-CO_2-He and on clinopyroxenes from Hyblean mantle xenoliths characterized by pure CO_2 inclusions. Blank measures were carried out on the glasses and on the mineral by ablating portions of solid matrix being microscopically free from FI. As concerns the experimental glasses, the ablation tests only involved helium measures. These analyses have led to poorly confident results due to the limited visibility of the bubbles (mainly in the basaltic glass) and to the too low gas content, resulting in a signal not easily distinguishable from that of the matrix. More promising results have so far been achieved by the analyses of the CO_2-dominant inclusions from Hyblean xenoliths pyroxenes, which involved both He and Ar measures. Generally, the fluid inclusions in the minerals of Hyblean xenoliths are distributed in micro-bubbles plans related to healed fractures. In order to collect a larger gas amount and obtain a signal suitable for the analyses, we carried out more ablations for each FI plans. We measured ^4He, ^{40}Ar and ^{36}Ar concentrations up to 1.9×10^{-15}, 1.7×10^{-16} and 3.0×10^{-19} mol for ablation set, respectively. The ^4He and ^{40}Ar signal from the ablated inclusions resulted clearly distinguishable from that of the blank (higher of one order of magnitude). A lower accuracy of the analyses was obtained in the estimation of ^{36}Ar as the bubbles signal resulted only twice that of the blank. The measured argon was corrected by atmospheric contribution using the obtained $^{40}Ar/^{36}Ar$ ratio of about 600 and provided a corrected $^4He/^{40}Ar^*$ of about 20. The $^{40}Ar/^{36}Ar$ and $^4He/^{40}Ar^*$ ratios from LA-MS tests result consistent with values of the FI bulk measured by crushing of few grams of clinopyroxenes. Next analyses will be addressed to estimate the He and Ar content in the single or small groups of FI from Etnean crystals of the primitive eruption previously investigated with regard to He-Nd-Sr isotopes and trace element composition.

Seismic anisotropy at Mt. Etna for the 2006-2011 seismic database

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Shear wave splitting, or birefringence phenomenon, occurs when a shear wave enters an anisotropic medium: the S wave splits into 2 quasi shear waves that have approximately orthogonal polarizations and different velocity propagation, never reconstructing the original waveform. The two observables associated with this phenomenon are: td, the time delay between the q_{S1} and q_{S2} onsets, and φ, the azimuthal polarization of the faster split shear wave in the horizontal plane. φ is parallel to the main (fast) orientation of the anisotropic volume, whilst the other splitting parameter td depends upon the integrated effect of anisotropy along the travel path. Investigations on seismic anisotropy, caused in the upper crust by aligned cracks that open and close in response to changing stress conditions measurements, allow to reconstruct the maximum stress orientation direction acting on the investigated area; td measurements, depending on the crack density and aspect ratios, give some roughly indication on the amount of the acting stress field. A great debate exists in the scientific literature on the role of the shear wave splitting parameters time variations as precursors of impending earthquakes or eruptions. Despite the theoretical approach gives evidence that the splitting parameters may give information on the time variation of the acting stress field, that is the primary cause of occurrence of both earthquakes and volcanic eruptions, experimental studies show that mainly splitting parameters time variation associated with the occurrence of volcanic eruptions are more coherent stable and favourable respect to the earthquakes case. We measured the Shear Wave Splitting (SWS) parameters for a huge dataset including volcano-tectonic earthquakes occurred at Mt. Etna in the period 2006 – 2010 and recorded at 38 stations. After performing accurate P and S wave picking of the recorded seismicity, SWS parameters has been evaluated using the semi-automatic SPY code by Zaccarelli et al. [2012]. The algorithm requires as input selected event seismograms, their hypocentre locations, and P and S arrival times and, working in a semi-automatic way. SPY computes, the polarization of the fast S-wave, by diagonalizing the covariance matrix representative of the seismic signal in the chosen time window around the S waves, obtaining the first eigen-vector of the horizontal component, then, rotating the traces into the fast direction; the time delay td between fast and slow arrivals is estimated through cross-correlation. SPY has some internal selection rules that allow rejecting all the waveforms that do not exhibit clear S-phases on the basis of three criteria (horizontal component amplitude greater than the vertical one, S-wave amplitude well above the P-coda values, and high rectilinearity of the fast wave polarization). The obtained results have been checked in hodograms to avoid possible cycle skipping and other anomalous effects. Statistical tests on the parameters have been performed in order to consolidate the results achieved, interpreting them in terms of temporal and spatial variations of the volcanic activity.

New insights into the 2008-2009 Etna eruption from in-soil radon measurements and seismic activity

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One of the main aims of the WP5 Task 5.1 "Characterization of the threatening phenomena from space and ground" of the European MEDiterrranean Supersite Volcanoes (MED-SUV) project was the analysis of the Mt. Etna eruptive activity from a multidisciplinary perspective. In this paper, we take into account an eruptive event, which offers an intriguing case study to scrutinize the relationships between a few geochemical and geophysical parameters during a long-lasting (~15 months) lava emission. The eruption started on 13 May 2008, three days after lava fountaining, and finished on 6 July 2009. Based on continuous borehole measurements of in-soil radon (Rn) emission and ambient parameters (barometric pressure and air temperature measurements), we explore the variations of the gas before and during the eruptive activity in the light of local seismic activity, considering volcanic tremor and earthquakes. We can shed light on the dike intrusion that fed this eruption also exploiting an exceptional point of view, as the station for the Rn flux measurements is located on a fumarole at an altitude of 2950 m above sea level and near (~1 km) the summit active craters. Accordingly, this study offers new insights on the recharging phases that preceded and accompanied the 2008-2009 eruption.

First results from pattern classification applied to seismic data recorded at Piton de la Fournaise (La Réunion)

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Data mining tools were tested within the WP 5 - Task 5.1 "Characterization of the threatening phenomena from space and ground" of the European MEDiterrranean SUpersite Volcanoes (MED-SUV) project to tackle various classification and pattern recognition problems. These methods were successfully exploited for the identification of impending volcanic activity at Mt. Etna (Italy). Benefiting from the positive experiences acquired, we explored the application of one of these tools to seismic data recorded at Piton de la Fournaise (La Réunion) volcano, which the WP 7 "Pilot Phase - Validation and transfer of project outcome" of MED-SUV identified as ideal test site for the validation of innovative concepts for early-warning purposes. Our case study analyses the time span from 2014 to 2015, during which 5 episodes of lava fountains and lava flows occurred around the central cone. Their duration ranged from a few hours to about two months. For this application, we processed two years of continuous seismic data, providing a specific tuning of the software. We present our preliminary results considering the frequency content of the background seismic radiation at the broadband 3C station RVL, which was located close to the base of the central cone and to the eruptive centres. Results of pattern classification applied to seismic data recorded during eruptive episodes at Mt. Etna are also presented for comparison.

Inferences into the volcanic system of Mt. Etna (Italy) through geochemical pattern classification of volcanic products erupted from 1995 to 2013

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In this paper, we present the results of the application of pattern classification to the bulk rock composition (based on 13 major and trace elements) of volcanic products erupted by Mt. Etna volcano, Italy. The software for pattern classification belongs to the data mining tools developed within the WP 5 - Task 5.1 "Characterization of the threatening phenomena from space and ground" of the European MEDiterrranean SUpersite Volcanoes (MED-SUV) project. The analysed samples are the products of Strombolian explosions, lava fountaining, and lava effusion during summit and flank eruptions from 1995 to 2013. The results of pattern classification allow us to visualize quickly in a single diagram changes in magma composition over the 18 years covered by these products, providing useful insights into magma dynamics within the plumbing system of the volcano and their possible relationship with the features of volcanic activity. In particular, our data highlight important compositional changes of products erupted during the long-lasting flank eruptions. According to literature data, these changes can be explained by the ascent of primitive, deep magma that mixes with the magma feeding the ongoing eruption, changing the composition of the erupted products. Concerning the summit activity at the four craters Bocca Nuova, Voragine, North-East- and South-East Crater, pattern classification indicates that no crater had a "typical" magma. This suggests that all the summit craters were fed by a common magmatic reservoir, and that magmatic processes (fractional crystallization) in limited portions of the shallow plumbing system likely drove the variations of magma composition in time. Finally, among the summit craters, the South-East Crater and its new cone, the New South-East Crater formed in 2011, were active almost continuously for a long time giving us the opportunity to investigate the magmatic processes that control the compositional variations of products erupted during the lava fountains in 2000, 2007-08, and from 2011 to 2013.

Multi-parametric investigation of Mt. Etna 2014 eruption: evidences for interconnected dynamics at multiple vents

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On 5 July 2014, a new eruptive fissure (hereafter EF) opened on the eastern flank of Mt. Etna volcano, at the base of North East Crater (NEC). The activity was characterised by Strombolian explosions from two neighbouring vents and the effusion of lava. This activity allowed for the growth of two few tens of meters high cones. On 16 July, in the framework of the MED-SUV project, we performed a multi-parametric investigation of this explosive activity at the two vents (here defined crater N and crater S, distance = ca. 40 meters) by means of a dense instrumental network. The setup, deployed at ca. 300 m from EF, comprised 2 broadband seismometers, 3 microphones as well as high speed video and thermal cameras. The analysis of the thermal images allowed for a comparison of the activity at each eruptive vent. Indeed, for each crater, we derived a series of thermal transients, marking the arrival of the incandescent gas/pyroclasts at the crater rim. Successively, we applied a percentile-based method to detect individual explosions. Hence, we were able to define the eruptive history and style at each crater. Additionally, the inter-arrival time of explosive events was evaluated and compared with the estimates performed on acoustic recordings. During the investigated time, Crater N was characterized by Strombolian activity (recurrence time: 2.26 s) whereas Crater S alternated Strombolian explosions with puffing (recurrence time: 1.44 s). Nonetheless, the overall variation in the recurrence time and amplitude of explosion at the two vents correlates fairly well. The goodness of such relationship was evaluated by the randomized cross-correlation method indicating that the activity at the two vents is not independent, thereby suggesting a shallow partitioning in the plumbing system.

Sulfur solubility in Etnean basalts constrained by melt inclusions and experiments

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Mount Etna is a complex volcanic system showing a great variability in the eruptive style and in the composition of erupted products. It continuously releases enormous quantity of gas, among all the SO_2 (daily average ~3500 tons), that plays an important role in the atmosphere chemistry. We present here the results of a melt inclusion study coupled to an experimental investigation of the S solubility in hydrous alkali basalts from Etna. Olivine-hosted melt inclusions were selected from 6 eruptions of the last 14 ky. The most primitive are FS (with picritic bulk composition, and Fo^{91} olivine phenocrysts) and Mt. Spagnolo, products of more recent eruptions (2002/3, 2006, 2008/9, 2013) have been also investigated. The glass inclusions show variable volatiles content, especially for S, from a few hundred ppm in recent lavas up to 4000 ppm in the oldest Mt. Spagnolo products (Fo^{88}). The variability in S concentrations is mainly correlated with the evolution of the melt, as highlighted by the major element (SiO_2, K_2O) chemistry of the inclusions, and, to a lesser extent with degassing processes. The finding of sulphide globules in melt inclusions from recent eruptions (2006, 2008/9, 2013), the occurrence of Cr-spinel in FS and Mt. Spagnolo basalts, and mostly, melt Fe^{3+}/Fe_{tot} values determined by XANES spectroscopy demonstrate a large range of redox conditions for the Etna magma. The Fe^{3+}/Fe_{tot} ratio decreases from the FS inclusions toward the most recent eruptions, suggesting a decrease in fO_2 that could also affect S incorporation and gas/melt partitioning. In order to better constrain the S variations in the melt inclusions, the experiments have been performed on hydrous mafic melts from Etna at sulphide saturation (SCSS), T=1200 °C, P= 200MPa, and fO_2 0.3-0.8 log units above the NNO buffer. Experimental results show the prevalent role of fO_2 and melt FeO_t concentration in controlling the S content (at SCSS) in Etnean melt. Together with the XANES information, the experimental results provide constraints on the redox conditions of the Etna magmatic system.

Borehole experiment at Pozzo Pitarrone, NE flank of Mt. Etna Volcano: preliminary results of 3D array analysis

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In volcanic environment the shallowest few hundred meters of rock are usually characterized by strongly variable mechanical properties. Therefore the propagation of seismic signals through these shallow layers is strongly affected by lateral heterogeneity, attenuation, scattering, and interaction with the free surface. As a consequence, tracing a seismic ray from the recording site back to the source is a complex matter, with obvious implications for the source location. For this reason the knowledge of the shallow velocity structure may improve the location of shallow volcano-tectonic earthquakes and volcanic tremor, thus contributing to improve the monitoring of volcanic activity. The use of high performance seismic stations, such as borehole instruments, may increase the signal to noise ratio (SNR), improving the capability to detect very small signals. This work focuses on the analysis of seismic noise and volcanic tremor recorded in 2014 by a temporary array deployed in the area called "Pozzo Pitarrone", NE flank of Mt. Etna, where two seismic stations of the local monitoring network are installed (Pitarrone borehole stations), one at surface and one borehole at a depth of about 130 m. We used data from the arrays installed, in order to analyse the dispersion characteristics of ambient noise vibrations and we derived one-dimensional (1D) shallow shear-velocity profiles through the inversion of dispersion curves measured by autocorrelation methods (SPAC).

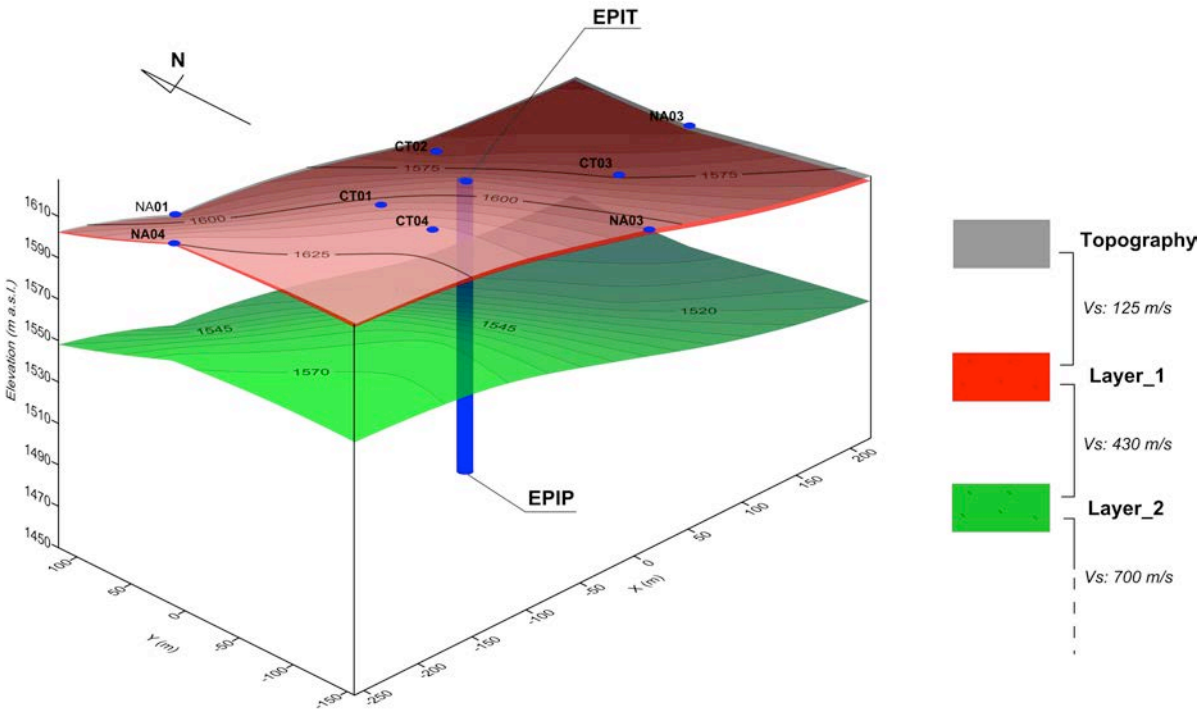

Figure 1. 3D stratigraphic model obtained by results of the single station inversions.

We observed a one-dimensional variation of shear-velocity between 430 m/s and 700 m/s to a depth of investigation of about 130 m. An abrupt velocity variation was recorded at a depth of about 60 m, probably corresponding to the transition between two different layers. A comparison of such model with the stratigraphic information available for the investigated area shows a good qualitative agreement. Taking advantage of a borehole station installed at 130 m depth, we could estimate also the P-wave velocity by comparing the borehole recordings of local earthquakes with the same event recorded at surface. Further insight on the P-wave velocity in the upper 130 m layer comes from the surface reflected wave observable in some cases at the borehole station. From this analysis we obtained an average P-wave velocity of about 1.2 km/s, compatible with the shear wave velocity found from the analysis of seismic noise. To better constrain the inversion we used the HVSR computed at each array station, which also give a lateral extension to the final 3D velocity model. The obtained results indicate that site effects in the investigate area are quite homogeneous among the array stations. The knowledge of a shallow velocity model could advance study of the source mechanism of the low frequency events (VLP, LP and volcanic tremor), and could give a new contribution to the seismic monitoring of Etna volcano through the detection and location of seismic sources by using 3D array techniques.

Relationship between eruptive activity and flank dynamics: the 8 December 2015 seismic swarm at Mt. Etna

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From 2 December 2015, volcanic activity suddenly occurred on Mt. Etna with very violent fire fountaining at central crater, known also as "Voragine". This activity continued with other intense episodes at the same crater during the three following days and involving also, in turn, all the other three summit craters. This sudden eruption produced a rapid deflation of the volcano and was followed, from 8 December, by a seismic swarm, with almost eighty earthquakes during this day, located on the uppermost segment of the Pernicana-Provenzana fault system (PFS). This seismicity was characterized by shallow foci (from few hundred meters until 1.5 km below the sea level) and main shock with 3.6 magnitude. In order to investigate and measure the dynamics controlling and accompanying the PFS activation, a dataset composed of C-Band Sentinel-1A data has been used for SAR Interferometry (InSAR) analysis. Some interferograms have been generated from ascending and descending orbits in order to analyse both short- and long-term deformation. The availability of GPS data allowed comparing and integrating them with InSAR for ground truth and modelling aims. The surface kinematics and modelling obtained by DInSAR and GPS data and integration have been compared to the distribution of the seismicity and related focal mechanisms in order to define the fault geometry and motion. Moreover, essential constraints have been achieved about the PFS dynamic and its relationship with the intense volcanic activity occurred.

Spreading and collapse of big basaltic volcanoes

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Among the different types of volcanoes, basaltic ones usually form the most voluminous edifices. Because volcanoes are growing on a pre-existing landscape, the geologic and structural framework of the basement (and earlier volcanic landforms) influences the stress regime, seismicity, and volcanic activity. Conversely, the masses of these volcanoes introduce a morphological anomaly that affects neighbouring areas. Growth of a volcano disturbs the tectonic framework of the region, clamps and unclamps existing faults (some of which may be reactivated by the new stress field), and deforms the substratum. A volcanos weight on its basement can trigger edifice spreading and collapse that can affect populated areas even at significant distance. Volcano instability can also be driven by slow tectonic deformation and magmatic intrusion. The manifestations of instability span a range of temporal and spatial scales, ranging from slow creep on individual faults to large earthquakes affecting a broad area. Our work aims to investigate the relation between basement setting and volcanic activity and stability at Etna (Sicily, Italy), Kilauea (Island of Hawaii, USA) and Piton de la Fournaise (La Reunion Island, France). These volcanoes host frequent eruptive activity (effusive and explosive) and share common features indicating lateral spreading and collapse, yet they are characterized by different morphologies, dimensions, and tectonic frameworks. For instance, the basaltic ocean island volcanoes of Kilauea and Piton de la Fournaise are near the active ends of long hotspot chains while Mt. Etna has developed at junction along a convergent margin between the African and Eurasian plates and a passive margin separating the oceanic Ionian crust from the African continental crust. Magma supply and plate velocity also differ in the three settings, as to the sizes of the edifices and the extents of their rift zones. These volcanoes, due to their similarities and differences, coupled with their long-time and high-level monitoring networks, represent the best natural laboratories for investigating the manifestations and mechanisms of spreading and collapse, the feedback process between spreading and eruptive activity (especially along rift zones), and the role of the regional geodynamics.

Effect of particle volume fraction on the settling velocity of volcanic ash particles: implications for ash dispersion models

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We report experimental measurements of the enhanced settling velocity of volcanic particles as function of particle volume fraction. In order to investigate the differences in the aerodynamic behaviour of ash particles when settling individually or in mass, we performed systematic largescale ash settling experiments using natural basaltic and phonolitic ash. By releasing ash particles at different, controlled volumetric flow rates, in an unconstrained open space and at minimal air movement, we measured their terminal velocity, size, and particle volume fraction with a high-speed camera at 2000 fps. Enhanced settling velocities of individual particles increase with increasing particle volume fraction (see figure).

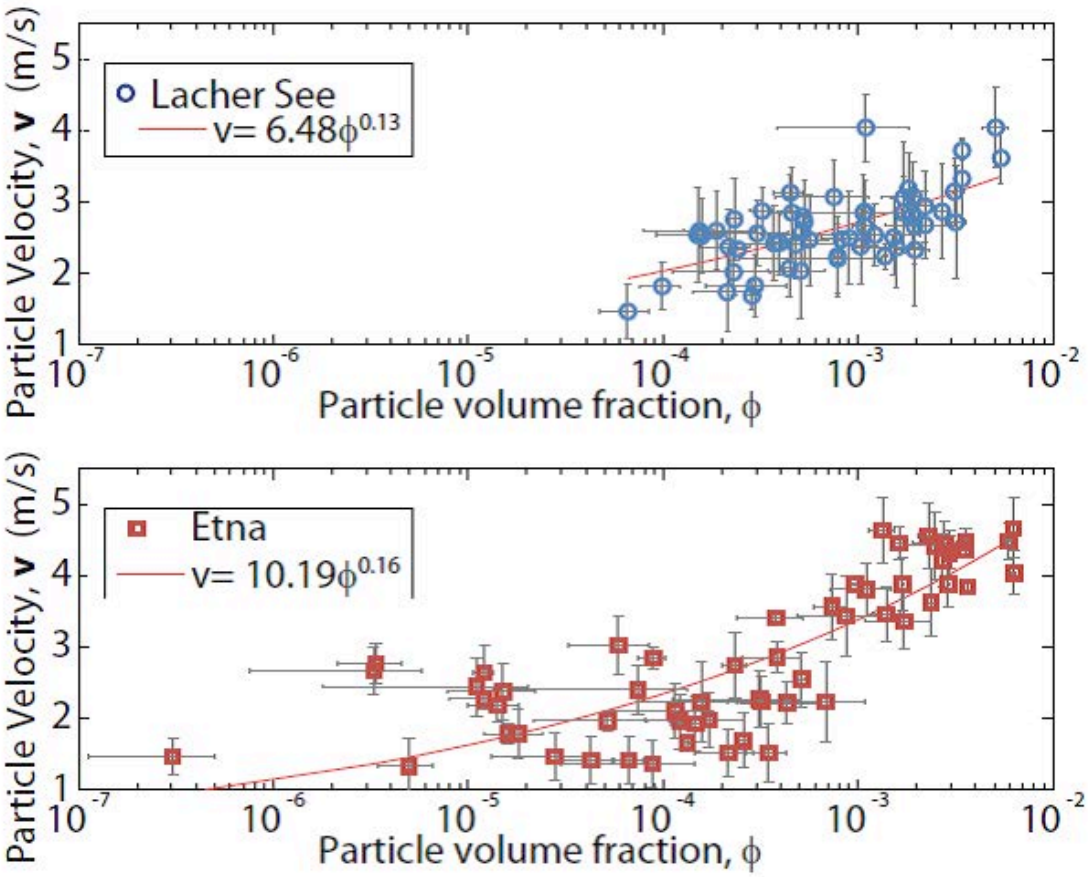

Figure 1. Plotting particle velocity against particle volume fraction provides a power law relationship in the form v = kΦn, k and n being dependent on the density and size. Each point represents the v and Φ averaged over 40 frames sequences.

This suggests that particle clustering during fallout may be one reason explaining larger than theoretical depletion rates of fine particles from volcanic ash clouds. We provide a quantitative empirical model that allows to calculate, from a given particle size and density, the enhanced velocity resulting from a given particle volume fraction. The proposed model has the potential to serve as a simple tool for the prediction of the terminal velocity of ash of a hypothetical distribution of ash of known particle size and volume fraction. This is of particular importance for advection diffusion transport model of ash where generally a one-way coupling is adopted, considering only the flow effects on particles. To better quantify the importance of the enhanced settling velocity in ash dispersal, we performed 3D numerical simulations (using the Discrete Particle Model DPMFoam of the open source software OpenFOAM) investigate the effect of particle volume fraction on the surrounding air. Particles with a normal size distribution are released in still air with zero velocity from the top of the domain. The incompressible Navier-Stokes equation is solved in an Eulerian frame and the transport equations in a Lagrangian frame for the continuous and the discrete (particles) phases, respectively. The two phases are coupled mostly through momentum transfer due to buoyancy and drag. We finally introduced the new formulation in a Lagrangian model calculating for realistic eruptive conditions the resulting ash concentration in the atmosphere and on the ground.

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WP6

Talks

Short-term Probabilistic Volcanic Hazard Assessment: a tool developed in MED-SUV project, applied to Campi Flegrei, Vesuvius and Etna for tephra fallout

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Probabilistic Volcanic Hazard Assessment (PVHA) represents the most complete scientific contribution for planning rational strategies for volcanic risk mitigation, at different time scales. The definition of the space-time window for PVHA is related to the kind of risk mitigation actions that are under consideration. While long-term (decades to centuries) assessment is required for land-use planning, short exposure intervals (hours to days or weeks) are important for short-term risk mitigation actions like the evacuation of an area. During volcanic unrest episodes or eruptions, it is of primary importance to produce short-term tephra fallout forecast, and frequently update it to account for the rapidly evolving situation both in terms of (i) volcanic activity (and consequently in terms of changing information coming from the monitoring system) and (ii) changing meteorological conditions (in particular, the wind field). This information is obviously crucial for crisis management, since tephra at the ground, even in small amounts, may heavily affect public health, transportations and evacuation routes (airports, trains, road network) and lifelines (electric power supply), as well as, for larger amounts, building stability. In the framework of MED-SUV project, we have developed a new methodology named BET_VH_ST for short-term PVHA applicable for volcanic tephra dispersal, based on (i) a translation of the measures from the monitoring system into anomalies, and (ii) output of simulators of tephra dispersal, from a representative set of vent positions and eruptive sizes, based on frequently updated meteorological forecasts. The model stems from deterministic procedures, and it deals with the large uncertainty that classical scenario-based procedures typically ignore, like uncertainty on the potential position of the vent, on the eruptive size and its related parameters that are input to simulators, on the possible evolution of volcanological input during ongoing eruptions, and on variable wind field and uncertain forecast. The large uncertainty at all the steps required for the analysis, both aleatory and epistemic, is treated by means of Bayesian inference alternative simulation procedures for tephra dispersal, and statistical mixing of long- and short-term analyses. The output of BET_VH_ST model is a set of hazard curves for each point of a target grid around the volcano. Each set describes the aleatory and epistemic uncertainties in the probability of exceedance of different thresholds of the selected intensity measure; in the case of tephra fallout, we use as intensity measure the load accumulated at the ground in kPa or in kg/m^2. The BET_VH_ST model has been applied to three target volcanoes of MED-SUV projects: Campi Flegrei, Vesuvius and Etna. As regards Vesuvius, we have retrospectively applied the BET_VH_ST hazard model to the MESIMEX simulation exercise carried out in October 2008. The results show that BET_VH_ST is able to produce short-term forecasts of the impact of tephra fall during a rapidly evolving crisis, accurately accounting for and propagating all uncertainties, and enabling rational decision making under uncertainty. During the VUELCO simulation exercise at Campi Flegrei (in February 2014) we were able to apply BET_VH_ST model in real-time for the first time, providing, at each time step of the simulation, a complete picture of the tephra fallout hazard within the Bulletins released by Osservatorio Vesuviano. The application to Etna is still ongoing. Here, we present the preliminary hazard model, in which we account both for central and lateral eruptions. The short-term probability of lateral eruptions (along with that of their size and of the position of their vents) is computed through BET_EF model, in which the monitoring parameters, thresholds and weight have been set by means of an elicitation experiment carried out in MED-SUV project among the Osservatorio Etneo and INGV-Palermo researchers. Eruption scenarios have been discretized into ten eruptive size/vent combinations, trying to cover the whole source space: four cases related to central eruptions (four sizes from summit vents) and six cases related to lateral activity (two sizes repeated at different vent elevations of 500, 1500 and 2500m). Vents at elevation larger than 2900m (central eruptions)

are assumed equiprobable; the spatial probability of lateral vents (at elevation lower than 2900m) has been taken from literature. Tephra dispersal for the ten scenarios has been simulated through HAZMAP, based on past wind distributions, in order to set a long-term seasonal reference for the related hazard. On the other hand, modelling based on weather forecast, are routinely performed for Etna. All these settings allow for a complete definition of BET_VH_ST for lateral eruptions. The implementation for central eruptions will require a further effort to perform expert elicitations for short-term eruption forecasting.

MED-SUV WP6 TASK 3 Capacity building and interaction with decision makers: Improving volcanic risk communication through volcanic hazard tools evaluation at Campi Flegrei Caldera (Italy) and Understanding volcanic risk perception of Civil Protection operators at Azores (Portugal)

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Focusing on volcanic hazard the goal of MED-SUV WP6 Task 3 is to improve the communication efficacy of scientific outputs, to contribute in filling the gap between scientists and decision-makers. In particular, scientific outputs, especially maps are fundamental sources of hazards and related at risk information. 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 experts even if decision makers. To face this issue, Campi Flegrei caldera, in Neapolitan area has been chosen as the pilot research area where to apply an evaluation/validation procedure to provide a robust evaluation of the volcanic maps and its validation resulting from end users response. The selected sample involved are decision makers and officials from Campanian Region Civil Protection and municipalities included in Campi Flegrei RED ZONE, the area exposed to risk from to pyroclastic currents hazard. Semi-structured interviews, with a sample of decision makers and civil protection officials have been conducted to acquire both quantitative and qualitative data. The outcomes analysis have assessed level of respondents understanding of content as displayed, and their needs in representing the complex information embedded in volcanic hazard. On the outcome bases we are collaborating with some of decisions makers in the development of a leaflet as "guidelines" that can support those understanding volcanic hazard and risk maps. The leaflet could be also adopted by stakeholders as communication tool in information program for the population at risk. In order to involve also Etna area in WP6 TASK 3.1 activities, a questionnaire developed in the VUELCO project (Volcanic Unrest in Europe and Latin America) has been proposed to Sicily Civil Protection officials having decision-making responsibility in case of volcanic unrest at Etna and Stromboli, to survey their opinions and requirements also in case of volcanic unrest, useful to finalize shared procedure and protocols. Furthermore as related to the Task 3 aim, a study on volcanic risk perception has been carried out at Azores (Portugal), In particular the survey investigates how various stakeholders involved in risk and disaster management perceive volcanic risk in terms of knowledge volcanic hazards and risk perception, hazard salience of, perceived preparation, capacity to manage volcanic crises, level and quality of information received. The results can contribute to both prepare for hazards and ease communication among stakeholders before, during and after emergency periods enhancing resilience. A 38 item questionnaire, adapted from instruments used previously in Italian sites, was used to collect data on 330 individuals from Civil Protection and several entities related to it, such as firemen corporations, police forces, health institutions or municipalities. Correlational statistical analysis is being used to explore relationships between sociodemographic variables and risk perception variables.

Developing long-term probability time models for the episodic volcanism of Campi Flegrei caldera (Italy)

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After the large scale event of Neapolitan Yellow Tuff (~15 ka BP), intense and mostly explosive volcanism has occurred within and along the boundaries of the Campi Flegrei caldera (Italy). Eruptions occurred closely spaced in time, over periods from a few centuries to a few millennia, and were alternated by periods of quiescence lasting up to several millennia. Often events also occurred closely in space thus generating a cluster of events. The most recent eruption was that of Monte Nuovo in AD 1538. There is a remarkable uncertainty on the eruptive record, affecting the time of eruptions, location of vents as well as the erupted volume estimates. This study had two main objectives: 1) to describe the record uncertainty by using a quantitative model and 2) to develop, based on the uncertainty assessment, a temporal probability model to describe the temporal and spatial eruptive behaviour of the caldera. In particular, the study adopts a time-space double stochastic non-homogeneous Poisson-type model with a local self-exciting feature able to generate clustering of events which are consistent with the reconstructed record of Campi Flegrei. Results allow to evaluate similarities and differences between the three epochs of activity as well as to derive eruptive base-rate of the caldera and its capacity to generate clusters of events. The temporal probability model is also used to investigate the effect of Monte Nuovo event on a possible reactivation of the caldera and to estimate the time to the next eruption under different volcanological and modelling assumptions.

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WP6

Posters

Elicitation Experiment at Mt. Etna Volcano: a preliminary stage of a shared knowledge

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WP6 of MED-SUV European Project aims at showing how the improvement of the monitoring system at the Italian Supersite volcanoes may contribute to better volcanic hazard assessment and to bridge the gap between science, mitigation and preparedness of volcanic disasters. On these grounds, the scientists and decision makers are working together trying to optimise procedures for improving mutual exchange of their information. Then, scientists have to define what is background vs anomaly (referring to monitoring) and have to relate these anomalies with the flank activity of Mt. Etna. To minimize the subjective feeling regarding an incoming event (i.e. a flank eruption), mostly related to the different timescales of occurring anomalies, we exploit a formal expert opinion elicitation. Among applications of this analysis, some adopt an equal-weighting procedure of the various experts, while others rely on different techniques for weighting expert opinions; in any case, the weighting of experts plays a fundamental part in the elicitation process. A Team of 58 experts from INGV (Osservatorio Etneo in Catania and Palermo Section), with sound knowledge and skills on Mt. Etna monitoring, was invited to answer to a questionnaire through multiple forms. The goal was to identify the monitoring parameters as input for the Bayesian Event Tree model for the probability of an impending flank eruption at Mt. Etna. Each form was associated with a node of the Event Tree: the first three forms listed 56 parameters (with geophysical and volcanological signatures) each, and each expert was asked to identify, among the 56 parameters, those indicative of unrest for flank eruption (first node), magmatic unrest (second node) and flank eruption (third node), along with thresholds to define anomalies, and their weights (only for nodes 2 and 3) indicating the perceived importance of each parameter. A fourth form asked to identify parameters indicative of the position of the lateral vent. The weighting of each expert was assigned through mutual and anonymous recognition among the pool. As a control experiment, we compared the results thus obtained with those based on an equal-weighting procedure. The Team was instructed through preparatory sessions, held from May to December 2014, and addressed to an online procedure at http://elicitazione-etna-lateral.bo.ingv.it/public/ website. This allowed experts to have longer time for thinking and consulting bibliography during the elicitation. More, results were immediately available, thus giving the possibility for subsequent discussions and for achieving a feedback from the experts. The latter is the core of the reproducibility of the elicitation experiment though following sessions, converging to a shared vision of the outcoming event tree. Elicitation I was active during 08-22 April 2015, and 40 experts (70% of the whole Team) completed the questionnaire. Each parameter received a score s that is the sum of the weights of the experts that selected it. We performed a Change-Point Analysis to identify two score thresholds, maximum sM and minimum sm, respectively. The parameters having received a high score ($s \geq sM$) were identified as fully relevant, whereas the parameters having received an intermediate score ($sM > s > sm$) were still identified, but with a lower relevance, equal to $pa = (s-sm)/(sM-sm)$. The parameters with low score ($s \leq sm$) were definitely rejected. Elicitation I shows that for Node 1, results obtained by mutual recognition weighting vs equal weighting are well correlated (with percentages 20-40%). Similar results appear for Nodes 2 and 3, with very few exceptions at the tail of the distributions. In general, 20 (out of 56; 36%) parameters do not trespass the minimum threshold sm. In detail, 2 (out of 16; 13%), 9 (out of 21; 43%) and 9 (out of 19; 47%) for Node 1, Node 2 and Node 3, respectively. Looking at the results relative to Node 4, the experts show higher confidence in locating the most probable vent by considering mostly the parameters indicative of impending eruption (Node 3; 14 parameters out of 29, i.e. 48%). Elicitation I represents a first step towards the setup of an event tree for forecasting flank eruption occurrence at Mt. Etna. Future eliciting sessions will be held with the aim to confirm present results for shared parameters or remove those showing a low convergence of opinions. Further, the present results were illustrated to the Expert Team, and a discussion followed, during which different points were considered. As relevant, the Team argued that tremor is not among the proposed parameters though being a key signal for alert issue at Osservatorio Etneo. Relative comments, with other very minor notes (e.g. the strain release

associated to the diffuse seismicity that usually foreruns and/or accompanies initial stages of a flank eruption at Mt. Etna), will work for a revision of the list of parameters that will be proposed in next Elicitation II.

Grain size distribution uncertainty quantification in volcanic ash dispersal and deposition from weak plumes

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We present the results of uncertainty quantification and sensitivity analysis applied to volcanic ash dispersal from weak plumes with focus on the uncertainties associated with the original grain size distribution of the mixture. The Lagrangian particle model Lagrangian Particles Advection Code is used to simulate the transport of inertial particles under the action of realistic atmospheric conditions. The particle motion equations are derived by expressing the particle acceleration as the sum of forces acting along its trajectory, with the drag force calculated as a function of particle diameter, density, shape, and Reynolds number. Simulations are representative of a weak plume event of Mount Etna (Italy) and aimed at quantifying the effect on the dispersal process of the uncertainty in the mean and standard deviation of a lognormal function describing the initial grain size distribution and in particle sphericity. In order to analyze the sensitivity of particle dispersal to these uncertain variables with a reasonable number of simulations, response surfaces in the parameter space are built by using the generalized polynomial chaos expansion technique. The mean diameter and standard deviation of particle size distribution, and their probability density functions, at various distances from the source, both airborne and on ground are quantified. Results highlight that uncertainty ranges in these quantities are drastically reduced with distance from source, making them largely dependent just on the location. Moreover, at a given distance from source, the distribution is mostly controlled by particle sphericity, particularly on the ground, whereas in air also mean diameter and sorting play a main role.

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WP7

Talks

Integration of satellite data and images acquired from ground-based camera network for the extraction of lava flow evolution maps

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Lava flow evolution maps can be obtained from the analysis of data acquired with proximal sensing methods (i.e. ground-based techniques based on photogrammetric or laser scanning approaches) and satellite remote sensing data (i.e. Differential Interferometry Synthetic Aperture Radar and Stereo Photogrammetry). Ground-based techniques can be characterized by higher accuracy but limited ground coverages, while aerial and satellite data can cover wider areas and thus are more suitable for monitoring long lasting and widespread processes that propagate along the volcano slopes, such as the lava flow eruptions. Ground-based techniques require an adequate positioning of the sensors in a site from which it is possible to have an open view (without morphological obstacles) of the whole area of interest or alternatively to have a number of different observation points to cover the whole area. The information extracted from ground data can be used to downscale the wide-area information derived from aerial and satellite data or to integrate the maps in case of incomplete coverage or missing acquisitions (both due to low revisiting time or bad geometrical conditions). In this work, lava flows evolution maps derived from high resolution optical (WorldView II and Pleiades) and radar (COSMO-SkyMed and TerraSar-X) satellite data, made available within MED-SUV, were compared and combined with the maps obtained from the ground based visible and thermal images collected by the INGV-OE surveillance camera network (Etna_NETVIS). The maps were extracted using the tool developed in the framework of WP2 (ST 2.2.3). The outcomes of the analysis permit to assess the integrated capability of the ground-based and satellite sensors to monitor the evolution of fast evolving lava flows that propagate along the volcano slopes and can contribute to improve hazard assessment evaluations. Test cases were selected among the recent Etna paroxysmal events started in 2011, based on the availability and quality of the data acquired by the Etna_NETVIS and on EO visible and radar satellite data (SAR&HR_VIS). The maps obtained using NETVIS tool were useful in WP5 to "improve the interpretation and modelling of the mechanisms of cone-forming explosive activity and lava flow emplacement. Observing the time-evolution of the discharge rate trend for eruptions having different styles can contribute to understand lava flow expansion patterns in function of both lava flux and cooling rate of the lava surface". The approach developed for Etna was applied to other MED-SUV test site basaltic volcano - Piton de La Fournaise - where lava flows were mapped using both aerial and ground based-images, and satellite SAR coherence maps.

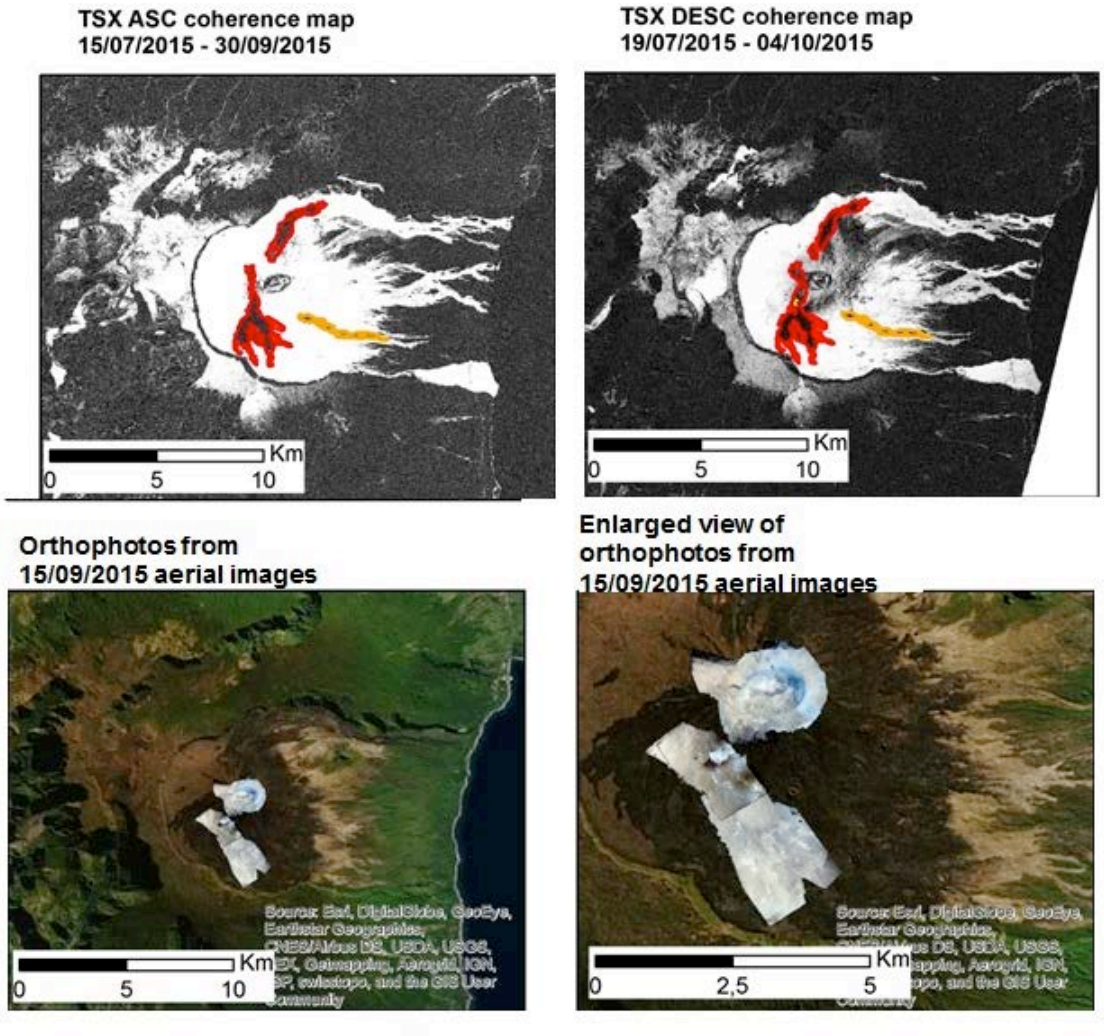

Figure 1. Piton de La Fournaise - Lava flows mapped using both aerial and satellite SAR coherence maps.

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WP7

Posters

Application of the GA for multiple deformation sources inversion at Fogo (Azores)

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Volcanic deformation is often observed at many active volcanoes in the world by space geodesy techniques, namely GNSS and InSAR. More difficulties in judging if eruption is imminent or not arise when such phenomena occur at dormant volcanoes due to the lack of eruption experiences followed by monitoring data. The eruption triggering mechanism is still controversial at many cases, but many attempts to image deformation sources beneath volcanoes have been made utilizing geophysical inversion techniques. In this study, we show the case study of Fogo (Agua de Pau) volcano, S. Miguel Island, Azores which represents over 450 years of eruption dormancy since 1563-1564. In the recent decades Fogo has exhibited three prominent seismic unrest episodes (1989, 2003-2006, and 2011-2012). The lack of geochemical and hydrothermal evidences for a magmatic intrusion during those episodes discourages the discussions on resuming volcanic activity of Fogo. However, the changes of the volcanic edifice, namely inflation/uplift are evident at least for the last two unrest episodes based on GPS data by Trota et al. [2009] and by Okada et al. [2015], respectively. The preliminary deformation modelling based on the repeated GPS campaign data suggested shallow expanding spheroid [Trota et al., 2009] or a single Mogi sources beneath the summit caldera. We performed more integrated inversion for the 2011-2012 episode using genetic algorism optimizing the source parameters. The best fit model agrees well with the reginal/local tectonic lineament suggesting the close relation between the volcanic sources and the reginal/local tectonics. The regional extensional stress (between Eurasia and Nubia plates) may play important roles for the ascent of volcanic fluids at Fogo volcano. We do not discard the possibility that Fogo may have been preparing for eruptions by intermittent ascents of volcanic fluids at shallow crust (i.e. experiencing “failed eruptions”) during the apparent dormant period.

Three-dimensional Audio-Magnetotelluric Imaging of the Furnas Caldera and hydrothermal area (Azores archipelago, Portugal)

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The Furnas volcano is the eastern-most of the three active central volcanoes of Sao Miguel Island. The main caldera formed about 30 ka BP, followed by a younger eruption at 10-12 ka BP, which forms the steep topography of more than 200 m in the measuring area. It contains several very young eruptive centres, and a shallow caldera lake. Tectonic features of varying directions have been identified in the Caldera and its vicinity. In the northern part of the caldera, containing the fumarole field of Caldeiras das Furnas, a detailed map of surface CO_2 emissions was made. In 2015, a pilot survey of 13 Audio-MagnetoTelluric soundings (AMT) and Electrical Resistivity Tomography (ERT) data (in the frame of MED-SUV WP7) were collected along two profiles in the eastern part of Furnas Caldera in order to image the electrical conductivity of the subsurface. The data quality achieved by both techniques is extraordinary and first results indicate a general correlation between regions of elevated conductivity and the mapped surface CO_2 emissions, suggesting that they may both be caused by the presence of hydrothermal fluids. Both, topography and bathymetry of the Atlantic Ocean can be expected to influence the results of the geoelectrical imaging of the Caldera. While topography and the known bathymetry of the lake were explicitly included in the model, we investigated the potential role of the ocean by forward modelling. For this purpose we designed a simple 3-D resistivity model for the island, with seawater resistivity values of 0.3 ohm-m extending to a depth of approximately 6,000 m and a (conservative) uniform land resistivity value of 100 ohm-m. The results show that the ocean effect is absent at periods less than 2 s. This legitimizes the use of a 3-D model incorporating only high-resolution topography and the bathymetry of the lake for our AMT data. However, the ocean effect will be a challenge for the interpretation of the long-period measurements (up to several 1000 s), which are planned for 2016. Based on these forward modelling results, the resistivity structure of the Caldera and the hydrothermal area has been imaged by first three-dimensional (3-D) inversions of the AMT data using ModEM inversion code. Data from 12 stations from the 2015 survey were used in the inversion process. Apart from very shallow anomalous zone near the Caldeiras fumarole field and below the southwestern part of the lake, the most interesting feature in the final resistivity model is a deeper, slightly westward dipping very low resistivity structure (< 3 ohm-m). An interpretation of the origin of this structure is in progress.

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