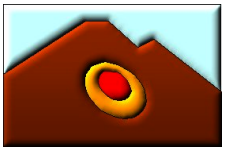
PROJECT TITLE

TECHNOLOGICAL INNOVATION AND AUTOMATION IN THE INTEGRATED APPLICATIONS OF ELECTROMAGNETIC AND POTENTIAL FIELD METHODS IN ACTIVE VOLCANIC AREAS



Scientific Coordinator
Name-Position: Ciro Del Negro – Senior Researcher
Affiliation: Sezione di Catania, INGV – Piazza Roma, 2 – 95123 Catania
Acronym: EPOT

ACTIVITY REPORT – 2nd YEAR

PROJECT PARTICIPANTS

RU#	***Affiliation***	***Responsible***
A.1	Dip. di Scienze Fisiche, Università di Napoli	Domenico Patella
A.2	Dip. di Geologia, Paleontologia e Geofisica, Università di Padova	Annalisa Zaja
A.3	Dip. di Geologia e Geofisica, Università di Bari	Domenico Schiavone
B.1	Sezione di Roma 2 - Istituto Nazionale di Geofisica e Vulcanologia	Antonio Meloni
B.2	Ist. di Metodologie Avanzate di Analisi Ambientale – CNR, Potenza	Vincenzo Lapenna
B.3	Dip. Elettrico, Elettronico e Sistemistico – Università di Catania	Giuseppe Nunnari
B.4	Dip. di Geofisica e Vulcanologia, Università di Napoli	Maurizio Fedi
C.1	Sezione di Catania - Istituto Nazionale di Geofisica e Vulcanologia	Gennaro Budetta
C.2	Sezione di Catania - Istituto Nazionale di Geofisica e Vulcanologia	Ciro Del Negro
C.3	Dip. Elettrico, Elettronico e Sistemistico – Università di Catania	Luigi Fortuna

GENERAL OBJECTIVES

The aim of the project is the application of a multi-methodological geophysical approach, which integrates the electromagnetic and potential field methods in contributing to the understanding of the physical structure and dynamics of active volcanoes. In order to achieve these objectives it is planned to improve the investigative power of the electromagnetic and potential field methods through:

(i) development of suitable methods of integrated inversion;
(ii) application of advanced technologies to process continuously recorded signals;
(iii) automation of monitoring and management systems and of surveys in real time.

ORGANIZATION

The review of the Evaluation Committee on the First Year of Activity of the project EPOT was generally favorable, in spite of the late start of the project because of delayed funding under Poseidon. On October 30, 2001 the Committee gave several recommendations for the implementation of the second year, which was approved with a reduced budget. Unluckily, it was possible to fulfill only a few recommendations during the second year of the project due to the continuous delay of the funding:

Funding timetable:

first year: first tranche was paid out on **April 2001**;
second tranche was paid out on **August 2002**;
second year: first tranche was paid out on **July 2002**;
second tranche was not paid out yet.

Taking advantage of own funds some activities, as algorithms implementation, have already developed (see Tasks 2 and 3). Instead, it was not possible to organize the whole proposed fieldwork and we propose to delay of just a few months the second part of the fieldwork (see Task 1). If the planned financial management will be observed during the last part of the project we will be able to attain the most final objectives.

The management during the second year of the project was centered on 4 points:

1) In 2001 was activated a Ph.D in Electronic Engineering and Automation (paid funded by the project) to deal with the automation of monitoring and management systems and of surveys in real time. The Ph.D. was assigned to Engineer Gilda Currenti and was planned in such a way to develop the study activity at the University of Catania (coordinator Prof. L. Fortuna) and the research activity at the *INGV-Sezione di Catania* (tutor Dr. C. Del Negro). Since October 2002 Gilda Currenti's been working at the USGS Long Valley Observatory in Menlo Park, California, for a 4 months stage in the team of Malcom Johnston.

2) At the end of 2001 a convention was stipulated with the University of Catania (Electrical, Electronic and Systemistic Department) to structure at the *INGV-Sezione di Catania* a new laboratory called "*Laboratorio di Tecnologie dei Sistemi Dinamici per la Geofisica dei Vulcani*" (**TecnoLab)**. The aim of this laboratory is to become the scientific and technical training centre of specialised staff working full-time in the monitoring of Etna volcano. In 2002 within **TecnoLab** were assigned some degree thesis and two Ph. D. in Electronic Engineering and Automation, whose one was partially paid. The Ph.D. tasks are:

Figure – TecnoLab plate.

a) Study, fabrication and applications of new materials for detecting deformations (see RU C3);
b) Complexity into geomagnetic signals (see RU C2).

3) A web site for the project is available at the address: **http://maglab.ct.ingv.it/epot** since July 2002. It is maintained by Geomagnetism Laboratory of *INGV-Sezione di Catania* and provides updated information about the project, proposed architecture, meetings, etc. As soon as possible, it will also contain a multi-parametric data bank making all data gathered within Epot project available to each partner. Coming soon *Epot site* should be linked to GNV site.

Figure – Epot site home page

4) Second year results were presented during the interim workshop held in Catania on 13 December 2002. During this meeting all partners also presented their objectives in the third year and discussion followed on how to ensure that the algorithms developed in this project are implemented in real-time monitoring procedures and can be used during volcano crises. The reports of each RU will be collected in a volume of extended abstracts and published before the 2003 General Assembly.

TASK 1 - PRELIMINARY 3D GEOPHYSICAL MODEL OF THE MT. ETNA VOLCANIC AREA

- (RU PARTICIPANTS: RU A.1, RU A.2, RU A.3)

- II YEAR OBJECTIVE

The task was to give a detailed description of the structural pattern of Etna, using self-potential, geoelectrical and magnetotelluric methods. The task has to be completed by acquiring further geoelectrical and magnetotelluric data in the SE crucial sector of the volcano.

- II YEAR RESULTS

A structural and volcanological model of the Mount Etna volcanic area is outlined using a 3D integrated analysis of existing gravity, dipole geoelectric, magnetotelluric and seismic data. Advanced 3D tomography and visualisation systems are applied for the first time in order to extract the maximum information content from the available datasets and to define, connect and assemble structures and related physical properties. All geophysical methods give reliable support to the existence of a dense, rigid and resistive structure in the central part of the volcanic area, as large as 10 km in the W-E direction, with a horizontal thickness of about 4 km in the N-S direction and extending from ground surface down to around 30 km of depth. The resistivity model shows on both sides of the W-E barrier the presence of two conductive zones in the depth range 15-30 km. Resistivities of a few Ωm are estimated in the southern conductive zone, while resistivities of a few tens Ωm are estimated in the northern conductive zone. A non-uniform feeding system is thus hypothesized as an extension of a previous ellipsoid-like uniform magma chamber model deduced from regional earthquakes and teleseisms in the depth range 15-25 km. Moreover, the comparison with intermediate and shallow depth seismic tomographies from local earthquakes within the first 16 km of depth allows a central high velocity zone to be distinguished inside the upper portion of the resistive barrier. This zone can likely be ascribed to a system of slowly cooled dikes tending to become highly fractured at the western and eastern edges. Finally, the impedivity analysis allows the existence of permanent shallow magma chambers to be excluded within the first 5 km of depth and to argue the existence of a shallow plumbing system hydrothermally altered at medium-to-low temperatures.

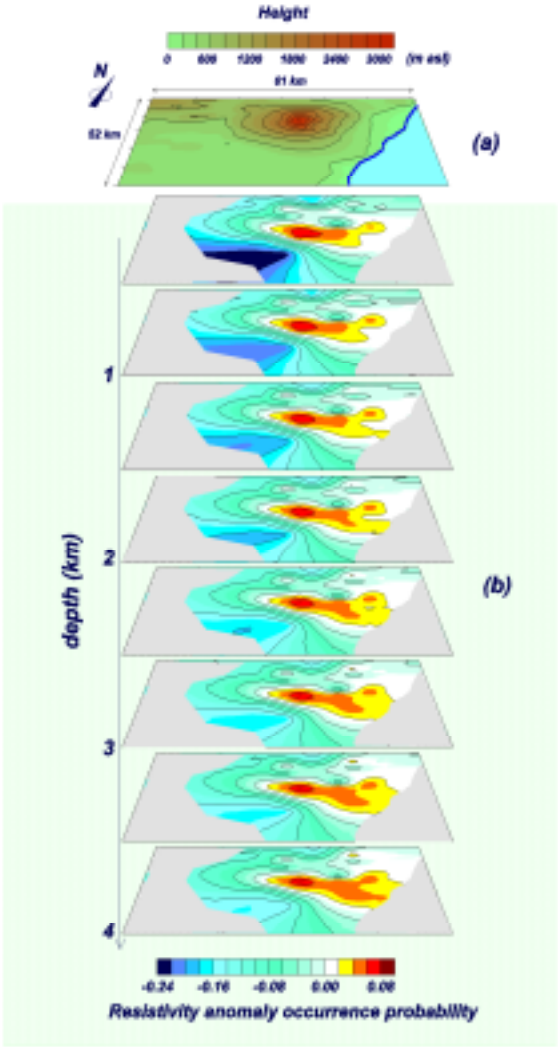


Figure 1 - (a): topographic map of the geoelectric survey area; (b): depth sequence of horizontal plots of the resistivity anomaly probability occurrence function.

- ***Methodology***

Integrated 3D probability tomography - A new tomographic method of source analysis of geophysical data was elaborated and applied. The theory has been developed and the computational algorithm has been tested for the 3D integrated probability tomography for every complex structural situation, buried below any irregular air-earth boundary. The new method has been successfully applied to the analysis of integrated geophysical data available for the volcanic area of Vesuvius, Etna and Vulcano [RU A.1].

- ***Data acquisition***

Electro-magnetic monitoring of volcanic activity - For the monitoring of active volcanic areas, the diagnostic capabilities of the Self-Potential (SP) and Magneto-Telluric (MT) methods have been started to be studied and assessed. The experimental activity has been concentrated only around the Vesuvius complex, because of the delayed availability of the funds [RU A.1].

- ***Processing and interpretation***

Magnetotelluric data processing - A robust processing code of magnetotelluric soundings was implemented and applied. The code was successful used to obtain data free of cultural noises, which often mask the deeper structures [RU A.2].

Gravimetric data processing - A new Bouguer anomaly was produced. The reprocessing consisted in the complete Bouguer correction of 948 gravimetric stations previously surveyed in the Etna area [RU A.3].

- RESEARCH PRODUCTS
  - n. 9 pubblications on international journals;
  - n. 1 invited paper at the 2001 EGS meeting and n. 2 presentations at international meetings;
  - software for the 3D integrated probability tomography;
  - computation codes for processing of Metronix data format time series as least-squares and remote-reference modes;
  - database of time series and impedance tensors of MT data;
  - database of edited apparent resistivity, phase, dimension parameters, 1D and 2D modelling results of MT data;
  - database of 3D MT forward models of Etna structure;
  - computation codes for the complete Bouguer correction.

- PUBLICATION LIST

Iuliano T., P.Mauriello and D.Patella, 2002: Looking inside Mount Vesuvius by potential fields integrated geophysical tomographies. *Journal of Volcanology and Geothermal Research*, vol.113, 363-378.

Iuliano T., P.Mauriello and D.Patella, 2002: Advanced magnetic visualization of the Mt.Vesuvius shallow plumbing system by probability tomography. *Annals of Geophysics*, vol.45, n.2, 431-438.

Loddo M., Schiavone D., Siniscalchi A., 2002. Generation of synthetic wide-band electromagnetic time series. Annals of Geophysics, 45 (2), 289-301.

Mauriello P., D.Patella, Z.Petrillo, A.Siniscalchi, T.Iuliano and C.Del Negro, 2002: A 3D geophysical model of the Mt.Etna volcanic area. In press on: The Mt.Etna Volcano, AGU Geophysical Monograph Series.

Vanorio T., M.Prasad, D.Patella and A.Nur, 2002: Ultrasonic velocity measurements in volcanic rocks: correlation with microtexture. *Geophysical Journal International*, vol.149, n.1, 22-36.

Vanorio T., M.Prasad and D.Patella, 2002: An experimental study of petrophysical properties of volcanic rocks from Etna and Phlegrean Fields. In press on *Journal of Volcanology and Geothermal Research.*

Mauriello P. and D.Patella, 2002: Magnetic buried sources discrimination by probability tomography. Submitted to *Geophysical Prospecting*.

Mauriello P. and D.Patella, 2002: Integration of geophysical methods by a generalized probability tomography approach. Submitted to *Geophysics.*

Mauriello P. and D.Patella, 2002: Introduction to tensorial resistivity probability tomography. Submitted to *Geophysical Prospecting*.

TASK 2 - TECHNOLOGICAL AND METHODOLOGICAL INNOVATION IN MONITORING OF VOLCANIC ACTIVITY

- (RU PARTICIPANTS: RU B.1, RU B.2, RU B.3, RU B.4)

- II YEAR OBJECTIVES

With a view to taking continuous gravimetric, magnetic and electrical observations to advanced levels for the volcano monitoring, it is necessary to speed up all the processes capable of refining the data acquisition techniques and improve the ability to recognize the "events" among the signals. The goals of the task may be summarized thus:

a) development and experimentation of instruments dedicated to working in volcanic areas;
b) application of advanced statistical methods to obtain evaluation criteria of gravimetric, magnetic and electrical signals reliability as precursors of volcanic events;
c) direct and inverse modeling performed simultaneously with the geophysical data acquired by multi-methodological observations.

- II YEAR RESULTS

The main objective of this task was the application of methodologies of nonstationary analysis to study the geophysical time series. Signal processing techniques over the past few decades have been dominated by the constraint of stationarity, a dominance which can be attributed to the simplification of problems arising from such an assumption. Consequently, non-stationarity is usually regarded as an undesirable feature, inasmuch as it significantly increases the complexity of a problem. Nevertheless, over the past few years it has been recognized that non-stationarity can actually be a useful feature. The purpose of this task is to discuss how non-stationarity can be utilized to produce superior results in existing problems attempted using the stationarity assumption. It contains new ideas for the processing of data with the potential of possibly easier detection of events in geophysical time series.

- ***Methodology***

Two advanced signal processing technique are applied to analyse the geomagnetic series. The first technique called CWTSA, is based on the continuous wavelet transform, the other one, called TVANS, is based on a time-varying adaptive algorithm (RLS). Both the methodologies have shown a remarkable resolutive ability to detect time variations that could be associated to seismomagnetic and/or volcanomagnetic effects. The CWTSA and TVANS allow recognising in geomagnetic signal well-localised events without to resort to time averages.

The CWTSA, based on the continuous wavelet transform of the difference of the geomagnetic series, allowed identifying rapid variations in the time. Thanks to this technique well-localised events connected to seismic and volcanic historical activity have been detected. The application of the TVANS also shows important variations of some historical parameters. Comparing the results from both techniques we find a substantial agreement either for the events to the eruptions of the Etna volcano or for the seismic activity recorded in the North Palm Springs.

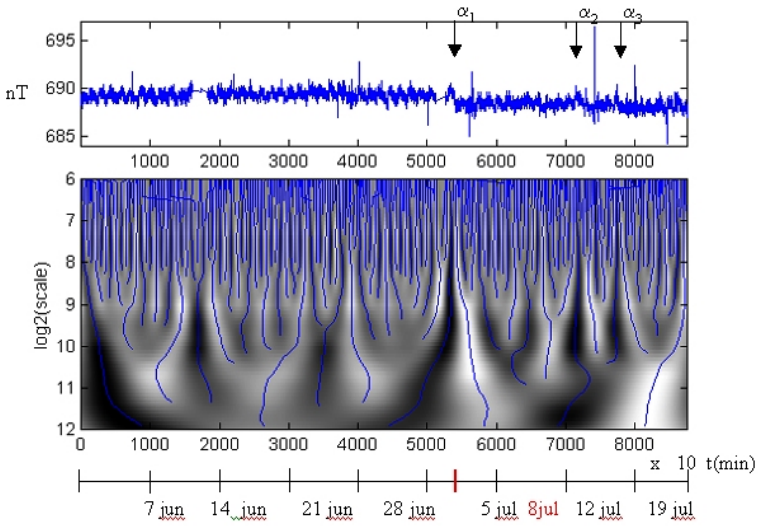


Figure – CWTSA and identification of the events.

These two techniques are able to detect particular periods in the time where the statistical characteristics of the signal change. This is a first approach to the general problem of the surveillance of a seismic and/or volcanic area. The future development of this research regards the application of the TVANS technique to multi-stations, in order to predict every signal from itself and the others will also projected to deal with the problem without necessarily perform the difference between the stations, obtaining many information from different sites simultaneously. As regards the CWTSA it will be utilised to try to supply a classifications of the sources in terms of the _ values that would result typical for each singularity [RU B.4].

Advanced statistical techniques were also developed to investigate the inner dynamics of geoelectrical and electromagnetic signals measured in volcanic areas and to discriminate extreme events from background noise. The attention was focussed to search scaling laws and to obtain an estimate of the predictability of the time series. To identify the presence of scaling laws were applied the Lomb Periodogram techniques and Detrended Fluctuations Analysis. The implemented techniques were applied and tested on the geoelectrical time series stored in the data-base available at Geophysical Laboratory of IMAA, that includes more than 200.000 experimental values measured in seismic active areas of Southern Italy [RU B.2].

- ***Modelling***

Joint inversion of magnetic and gravity data by soft-computing based techniques - At the present the inversions of ground deformation and magnetic data have been considered separately in order to study the peculiarities of the two inverse problems. The two considered inversion problems were formulated following a common scheme based on the use of a Multi-layer perceptron (MLP) neural network. To date, we have been implementing a software tool that allows solving the integrated inversion of magnetic and gravimetric data [RU B.3].

- ***Instruments***

Autolevelling tri-axial flux-gate magnetometer - A long period measurement was successful conducted to compare results of a prototype of our magnetometer with the data observed by the standard geomagnetic acquisition systems of the observatory. A simulation test of volcanic area measurements was performed in an area not far (40 km) from the L'Aquila Geomagnetic Observatory to test the complete measurement process [RU B.1].

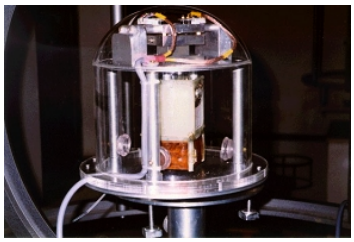


Figure – Magnetometer prototype.

- RESEARCH PRODUCTS
  - n. 4 publications on international journals;
  - n. 1 presentation at international meeting;
  - n. 11 publications on national journals, proceedings of national conferences, technical reports;
  - computation codes have been implemented for the integrated inversion of gravimetric, magnetic and deformation data;
  - design and implementation of n. 3 algorithms for searching scale invariance laws and identifying extreme events in geophysical time series.

- PUBLICATION LIST

Balasco M., V. Lapenna, L. Tedesca. 1/f fluctuations in geoelectrical signals observed in a seismic area of Southern Italy. *Tectonophysics*, 347, 253-268 (2002).

Cuomo V., G. Di Bello, J. Heinecke, V. Lapenna, G. Martinelli, S. Piscitelli and L. Telesca, Investigating the temporal fluctuations in geoelectrical and geochemical signals jointly measured in a seismic area of southern apennine chain (Italy), *Annali di Geofisica*, Vol. 44, N.2 179-191, (2001).

Fedi M., La Manna M., Palmieri F: Non stationary analysis of geomagnetic time sequences from Mt. Etna and North Palm Springs earthquake, Journal of Geophysical Reasearch, submitted.

Telesca L., V. Cuomo, V. Lapenna and M. Macchiato. A new approach to investigate the correlation between geoelectrical time fluctuations and earthquakes in a seismic area of southern Italy, *Geophys. Res. Lett*., vol. 28, n.23, 4375-4378 (2001).

Telesca L., V. Lapenna, M. Macchiato, Fluctuation analysis of the hourly time variability in observational geoelectrical signals. *Fluctuation and Noise Letters*, Vol. 2, N.3, 235-242, (2002).

Fedi M., Goncalves P., Johnston M., La Manna M, 2002: The identification of seismo- and volcano-magnetic events using non-stationary analysis of geomagnetic field variations. In Geophysical Research Abstracts, 27th EGS General Assembly, Vol. 4.

TASK 3 - NON-TRADITIONAL APPROACHES FOR THE AUTOMATIC PROCESSING OF DATA ACQUIRED BY VOLCANIC MONITORING NETWORKS

- (RU PARTICIPANTS: RU C.1, RU C.2, RU C.3)

- II YEAR OBJECTIVES

This task has been developing methods, hardware and know-how for the automated acquisition and management of data simultaneously acquired at a variety of remote sensors. In order to provide a basis for short-term decision-making in the forecasting and control of volcanic activity we have been designing and developing an automated system for volcano monitoring. This system aims at making the conditions for receiving and evaluating the data tuned to maximum efficiency and reliability. During the design phase attention was paid mainly to the following requirements:

1) Acquisition and transmission of a signal from a continuously recording sensor to a central observatory;

2) Reduction and evaluation of the incoming data to produce interpretable parameters and store the data in permanent files;

3) Comparison of the calculated parameters with prescribed limits and subsequent activation of a warning signal if the limits are exceeded.

- II YEAR RESULTS

Methodological developments - Several algorithms for numeric elaboration of signals to be used in a multi-resolution structure, working on data acquired in volcanic areas, have been implemented. Both linear and non-linear approaches have been used. Attention was paid to the following tasks:

Improvement of the signal-to-noise ratio - By the end of the present project we expect the quality of gravity and magnetic data coming from Etna continuously running stations to be strongly improved with respect to the early stages of the project itself. We have already designed a station setup, which proved to be suitable for acquiring high-quality gravity data against adverse environmental conditions. To further improve the setup an active thermosetting system is under development. Moreover, we are testing new strategies (using both polynomial and non-linear forms of different model structures) to correct data already collected for the effect of meteorological perturbations [RU C.1 and RU C.2].

Detection of anomalous events and eruption forerunners within the signal from continuous gravity stations - Once the gravity signal from continuously running stations is suitably reduced for the effect of external perturbations (which proved to be stronger by one order of magnitude than the volcanic effect) events with amplitude and/or characteristic anomalous with respect to the "normal" signal will be evidenced within each frequency band. Possible time correlations between such anomalous items and the volcanic activity will be also tentatively evidenced to define gravity forerunners of paroxysmal eruptive episodes [RU C.1].

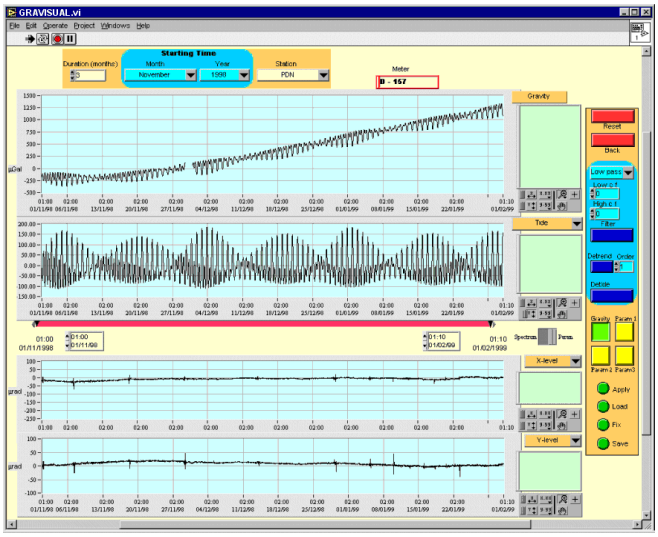


Figure – Software developed to quickly analyse long gravity data-sequences.

MADAP: MAgnetic DAta Processing - To handle rapidly the huge amount of data coming from stations of a monitoring network (e.g.: 8640 a day in each station, using a 10 s sample rate) and to apply different analysis techniques with the same speed we have developed a code, called MADAP (MAgnetic DAta Processing), which allows a high skill level to be achieved by the operator. MADAP includes a powerful, comprehensive package of analysis routines for processing acquired data. This package is rich in statistics, regressions, linear algebra, time and frequency domain algorithms, windowing routines, and digital filters. A number of dedicated routines to reduce magnetic disturbances are available in the package [RU C.2].

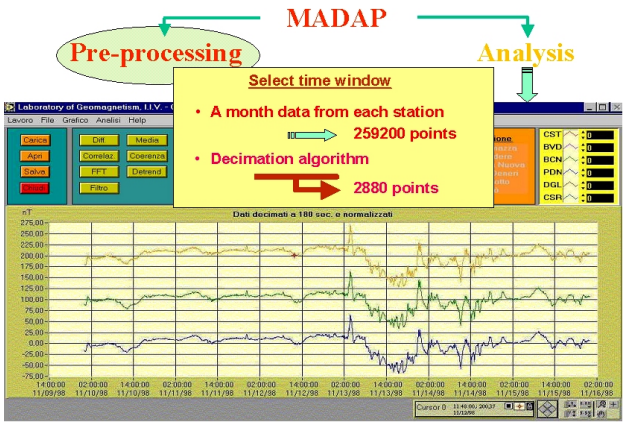


Figure – Software developed to process magnetic data sequences.

Modular system - In order to build a modular system, some tools have been implemented, utilizing the capabilities of Matlab® and LabVIEW™. Different strategies have been adopted to allow the effective elaboration of data of different nature. In particular both neural and neuro-fuzzy approach have been taken into account to face with the complexity of the considered phenomena. The tools for the automatic solution of the above mentioned tasks have been developed both for non-linear polynomial, neural, and neuro-fuzzy models [RU C.3].

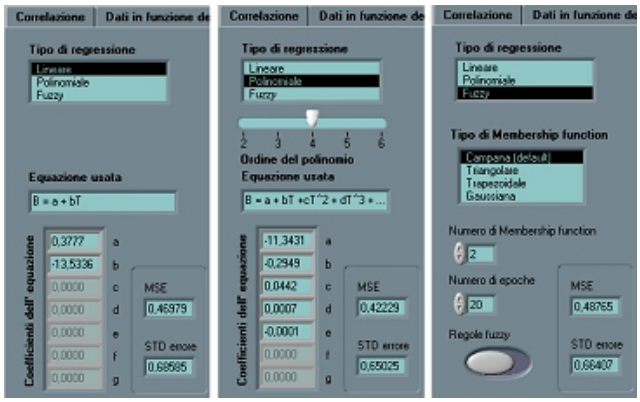


Figure – Cover of the system.

Such a characterization has to be considered as a preliminary approach. In fact, in accordance with the proposed activity, in the third year will focus on estimation of:

1. quality of the obtained models;
2. accuracy of results suggested by the developed system.

Complexity into geomagnetic signals - Geomagnetic fluctuations observed on the ground are closely interrelated to external magnetic fields of ionospheric and magnetospheric origins. Assuming that the magnetosphere evolves in a coherent and organized way, a low-dimensional analogue model was studied to understand its dynamics. Theoretical studies have shown that the magnetosphere belongs to the class of dissipative chaotic systems. Following on from this description of the magnetosphere, we applied an innovative method for chaotic dynamical system identification from measured data. We described geomagnetic activity in terms of a relatively simple nonlinear dynamical analogue model, whose parameters were determined in such a way that the simulated output signal synchronizes with the data acquired from the magnetic monitoring network at Etna volcano [RU C.2 and C.3].

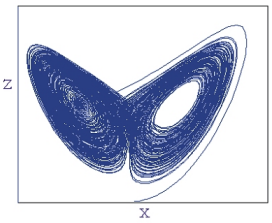


Figure – Lorenz attractor.

Study, fabrication and applications of new materials for detecting deformations - The activity deals with Electro-Active Polymers (EAP), in particular with Ionic Polymer-Metal Composite (IPMC). IPMC is an innovative "soft" and light material, which has the characteristic to bend if electrically stimulated, and, vice versa, to generate a voltage across its thickness if mechanically deformed both quasi-statically or dynamically. For these reasons they could be used as actuators or as sensors [RU C.2 and C.3].

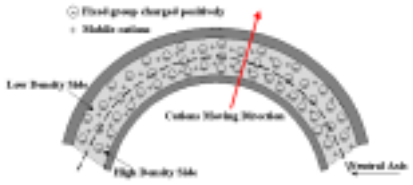


Figure - Effect of stress applied to the IPMC strip on mobile cations.

The idea is to produce a sensor able to detect deformation in a low frequency range. To do this at the beginning efforts were directed to improve the fabrication procedure of the IPMC. At this aim the **TecnoLab** has been equipped with all the instrumentation needed to make the metal deposition on the ionic polymer surfaces. Different samples have been made and tested and an optimal solution has been found. Then the activity has been moved from the fabrication to the characterization of the IPMC as sensor. Several measurements has been acquired and analysed. The IPMC has been

excited by different frequency and many other tests are currently under investigation. The first results show a good sensorial behaviour of the material: the voltage generated across an IPMC strip is proportional to the forced displacement and it depends also from the exciting frequency.
From now the work will regard the research of the law that links the input displacement (amplitude and frequency) to the output voltage in order to completely define the sensor characteristic.

- RESEARCH PRODUCTS
  - n. 12 publications on international journals
  - n. 8 presentations to international meetings (2 at 2002 EGS Assembly in Nice; 2 at 2002 MEEMSV Workshop in Moscow; 2 at 2002 AGU Fall Meeting in San Francisco;10th International Workshop NDCS in Minsk; IEEE CAS Society)
  - n. 3 presentations to national meetings
  - n. 2 data banks (gravimetric e magnetic)
  - n. 3 software packages

- PUBLICATION LIST

Bonomo, C., Del Negro, C., Fortuna, L., Graziani, S. (2002). Characterization of an IPMC strip's sensorial properties: preliminary results, IEEE CAS Society, submitted.

Budetta G., Carbone D., Greco F., Rymer H. (2002). Microgravity studies at Mount Etna (Italy), In "Etna Volcano Laboratory" (Eds. S. Calvari, A. Bonaccorso, M. Coltelli, C. Del Negro and S. Falsaperla), *AGU Geophysical Monograph series*, submitted..

Budetta G., Carbone D., Greco F., Rymer H. (2002). A continuously running mini-array for gravity monitoring of Mt. Etna (Italy). *Geoph. Prospecting*, submitted.

Carbone D., Budetta G., Greco F., Rymer, H. (2002). Combined discrete and continuous gravity observations at Mt. Etna. *J. Volcanol. Geoth. Res*., in print.

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Currenti, G., Del Negro, C., Fortuna, L., Vicari, A. (2002). Nonlinear Identification of Complex Geomagnetic Models: An Innovative Approach, *Journal NPCS*, in print.

Del Negro C., Napoli R., (2002). Ground and marine magnetic surveys of the lower eastern flank of Etna volcano (Italy), *J. Volcanol. Geotherm. Res.* 114/3-4, 357-372.

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Del Negro C., Ferrucci, F., Napoli R., (2002). Marine magnetic investigation of the submarine base of Mt. Etna and Iblei mountains, *Annals of Geophysics*, 45, 2, 361-374.

Del Negro, C. and Currenti, G. (2002). Volcanomagnetic Signals Associated with the 2001 Flank Eruption of Mt. Etna (Italy), *Geophys. Res. Lett.*, 2002GL015481, in print.

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Incoronato, A. and Del Negro, C. (2002). Magnetic stratigraphy procedures at Etna. In "Etna Volcano Laboratory" (Eds. S. Calvari, A. Bonaccorso, M. Coltelli, C. Del Negro and S. Falsaperla), *AGU Geophysical Monograph series*, submitted.

PROJECT TITLE

INTEGRATED GEOPHYSICAL METODS FOR THE STUDY OF VOLCANIC AREAS

Research Unit (RU) Responsible – RU A.1
Name-Position: Prof. Domenico Patella – Ordinary Professor of Applied Geophysics
Affiliation: Department of Physical Sciences, University Federico II of Naples

ACTIVITY REPORT – 2nd YEAR

RU PARTICIPANTS

Surname	***Name***	***Position***	***Affiliation***	***Man/month***
Patella	Domenico	Ordinary Professor	UNI NAPOLI Federico II, DSF	4
Mauriello	Paolo	Ordinary Professor	CNR-ITABC	2
Siniscalchi	Agata	Associate Professor	UNI BARI, DGG	2
Petrillo	Zaccaria	Researcher	INGV-OV	6
Iuliano	Teresa	PhD, Research fellowship	UNI BARI, DGG	2
Di Fiore	Boris	PhD, Research contract	UNI NAPOLI Federico II, DSF	6
Troiano	Antonio	PhD student	UNI NAPOLI Federico II, DSF	6
Di Giuseppe	M.Giulia	Research contract	INGV-OV	6

• 2nd YEAR OBJECTIVES

Integrated 3D probability tomography
The objective was to elaborate and apply a new integrated tomographic method of source analysis of self-potential (SP), geoelectric (GE), magnetotelluric (MT), magnetic (MG) and gravity (GR) data.

Electro-magnetic monitoring of volcanic activity
The objective was to study and assess the diagnostic capabilities of the self-potential (SP), dipolar Geoelectric (GE) and magnetotelluric (MT) methods to monitor the volcanic activity.

Structural characterisation of Etna and Vulcano
A first objective was to perform experimental field activities devoted to detailing the structural pattern of Etna, using GR, GE and MT methods. A second objective was to perform experimental field activities devoted to detailing the structural pattern of Vulcano, using SP and GE methods.

• 2nd YEAR RESULTS

Integrated 3D probability tomography
The method was expected to give meaningful results in every complex structural situation, below any irregular topography. The purpose was to improve the identification of the sources of anomalies in volcanic areas, and to locate their positions underground in a probabilistic sense, by integrating the datasets coming from geophysical methods sensitive to the same source body.
The theory has been developed and the computational algorithm has been fully tested. The new method has been successfully applied to the analysis of integrated geophysical data available in the volcanic areas of Vesuvius, Etna and Vulcano.

Electro-magnetic monitoring of volcanic activity
The experimental activity has been concentrated only around the Vesuvius complex, because of the delayed availability of the funds. The MT field has been monitored using the new Metronix system, acquired at the beginning of the year, after having previously performed all delivery and operational tests.

Structural characterisation of Etna and Vulcano
A new integrated interpretation of the GE and MT data on Mt.Etna has been carried out in order to remove static shift effects on MT curves and identify resistivity fequency-dispersion phenomena. An integrated analysis of repeated SP surveys at Vulcano has been done in order to identify long-standing streaming potential phenomena associated with

fluid migration (fumaroles). Moreover, a longitudinal dipolar GE profile crossing the whole island has been carried out, in order to detect the deep feeding structure of the volcano-geothermal system.

- RESEARCH PRODUCTS

  - n° 8 pubblications on international journals
  - n° 1 invited paper at the EGS meeting in Nice
  - n° 2 presentations at international meetings
  - software for the 3D integrated probability tomography

- PUBLICATIONS LIST

Vanorio, T., Prasad, M., Patella, D. and Nur, A., 2002: Ultrasonic velocity measurements in volcanic rocks: correlation with microtexture. *Geophysical Journal International*, vol.149, n.1, 22-36.

Iuliano, T., Mauriello, P. and Patella, D., 2002: Looking inside Mount Vesuvius by potential fields integrated geophysical tomographies. *Journal of Volcanology and Geothermal Research*, vol.113, 363-378.

Iuliano, T., Mauriello, P. and Patella, D., 2002: Advanced magnetic visualization of the Mt.Vesuvius shallow plumbing system by probability tomography. *Annals of Geophysics*, vol.45, n.2, 431-438.

Mauriello, P., Patella, D., Petrillo, Z., Siniscalchi, A., Iuliano, T. and Del Negro, C., 2002: A 3D geophysical model of the Mt.Etna volcanic area. In press on: The Mt.Etna Volcano, AGU Geophysical Monograph Series.

Vanorio, T., Prasad, M. and Patella, D., 2002: An experimental study of petrophysical properties of volcanic rocks from Etna and Phlegrean Fields. In press on *Journal of Volcanology and Geothermal Research*.

Mauriello, P. and Patella, D., 2002: Magnetic buried sources discrimination by probability tomography. Submitted to *Geophysical Prospecting.*

Mauriello, P. and Patella, D., 2002: Integration of geophysical methods by a generalized probability tomography approach. Submitted to *Geophysics.*

Mauriello, P. and Patella, D., 2002: Introduction to tensorial resistivity probability tomography. Submitted to *Geophysical Prospecting*.

PROJECT TITLE
MAGNETOTELLURIC AND ELECTROMAGNETIC SOUNDINGS ON MT. ETNA VOLCANO

Research Unit (RU) Responsible – RU A.2
Name-Position: Zaja Annalisa - University researcher
Affiliation: Dipartimento di Geologia, Paleontologia e Geofisica, Padova University (UniPD)

ACTIVITY REPORT–2nd YEAR

RU PARTICIPANTS

Name	Position	***Affiliation***	*man/month*
Annalisa Zaja	University Researcher	Dip. di Geologia, Paleontologia e Geofisica, Padova University	6
Nicola Praticelli	Technician	Dip. di Geologia, Paleontologia e Geofisica Padova University	3
Adele Manzella	Researcher C.N.R.	International Institute for Geothermal Research C.N.R. Pisa	2

- 2nd YEAR OBJECTIVES

Execution of seven MT soundings in remote reference mode, in the frequencies band: 300-1/300 Hz.
Execution of seven electromagnetic TEM soundings to remove the possible static shift on the magnetotelluric response curves.
The aim of the first two years of the projects is to record accurate MT soundings, in remote reference mode, in order to obtain data free of cultural noises, which often mask the deeper structures.

- 2nd YEAR RESULTS

During Fall 2001 eleven magnetotelluric (MT) soundings were recorded above the Etna volcanic area along a profile close to the area were the major eruptive fissures of the summer-2001 eruption are located. A remote-reference site was acquired simultaneously in a location of Calabria region where analogous measurements were acquired for Agip in the past with very good results, in order to be able to separate the possible local electromagnetic noise. The MT field work was commissioned to Metronix as a demostration, hence newly designed equipment was used for this campaign. At each site, the horizontal components of the electrical and magnetic fields were recorded in the frequency band between 20000-1/300 Hz.
A long time was spent to process data, since the data format was different from any other format used in the past by the partners of the projects. Some effort was required to process data since many bugs were found in the computation codes provided to this end. Eventually, the data could be processed in single-site mode, but any attempt to process remote-reference data failed due to a still unidentified reason. The only possible explanation the partners see is a technical problem during the acquisition, which de-synchronized the local and remote sites. The Metronix Company refuses such an explanation but is not able to give any different one.
Data were found affected by a strong electromagnetic noise, but the robust processing code that was used was able to separate very well the uncorrelated noise and the resulting data quality was found very good. The coherent noise possibly affecting the low frequencies could not be removed due to the above mentioned problem with the remote-reference processing.
After a very accurate data analysis, the apparent resistivity and phase curves were interpreted with a 1D modelling instead a 2D one as it seems a more appropriate interpretative approach looking at the morphology of the curves and taking into account the 3D geological conditions of the area. The results show an extended conductive structure at a depth of 3000-4000 m bsl. This feature was found very different from what defined in a previous MT field work in the same area, and would demonstrate the different structure of the volcano at different moments of its history.
A 3D MT forward modelling was then used to define the response MT curves for sites above this particular volcanic structure. This approach is very interesting in view of specific interpretative targets, such as dimension and position of the magma chamber, when planning future MT surveys. Altough the presence of even a small fraction of melt in the volume rock decrease the average resistivity of various tens of order of magnitude, the volume, position and overall condition of the magma chamber is critical

in view of its definition. Various sizes and depth of possible magma chambers were considered. The model comprised the presence of sea and the shallow structure was defined on the base of the experimental data.

- RESEARCH PRODUCTS

  - Computation codes for processing of Metronix data format time series as least-squares and remote-reference modes.
  - Database of Time series and impedance tensors of MT data
  - Database of edited apparent resistivity, phase, dimension parameters, 1D and 2D modelling results of MT data
  - Database of 3D forward models of Etna structure

- PUBLICATIONS LIST

PROJECT TITLE

3-D MODELING OF ETNA AND VULCANO-LIPARI GRAVIMETRIC DATA

Research Unit (RU) Responsible – RU A.3
Name-Position: Domenico Schiavone – Associate Professor
Affiliation: Dipartimento di Geologia e Geofisica – Università di Bari

ACTIVITY REPORT–2nd YEAR

RU PARTICIPANTS

NAME	POSITION	AFFILIATION	MAN/MONTH
Schiavone Domenico	Associate Professor	Dip. Geologia e Geofisica	4
Loddo Mariano	Ordinary Professor	Dip. Geologia e Geofisica	4

• 2nd YEAR OBJECTIVES

Reprocessing of the gravimetric data in the Eolian Islands

• 2nd YEAR RESULTS

The processed data (see figure) were both surveyed by the R.U. and obtained by a private company. The reprocessing consisted in the Bouguer complete correction using a spherical cap both for the Bouguer and the topographic corrections. In particular, a square "Inner Zone" with 5.0 km amplitude around each station and an "Outer Zone" with a radius of 167.735 km were used.
The databases adopted consisted in a 7.5"x10" DEM and in manually digitized topographic and bathymetric maps. For the inner zone correction a piecewise planar surface in form of triangular faceted surfaces is used as terrain model. The facets are constructed through a Delaunay triangulation using the digitized data. In this way any further approximation and processing of the original topographic data is not used. Triangular surfaces were also used to connect the mean elevation data representing the DEM database. The complete correction was carried out, for each gravity station, through triangular prisms on the basis of the Okabe relationship and considering, for the outer zone, the earth curvature and the influence of the sea. This last correction was also carried out, when necessary, for the inner zone.

• RESEARCH PRODUCTS

- The theoretical approach used for the complete Bouguer correction is the subject of a paper in preparation.
- Other products of the research consisted in the topographic and bathymetric databases and in the computation codes for the corrections.

• PUBLICATIONS LIST

Andriani, T., Balia, R., Loddo, M., Pecorini G. and Tramacere A., 1999: Inference of the main structural features of the Middle Tirso Valley (Central Sardinia-Italy) from gravimetric and geoelectric data and their relationships with the Tertiary. Submitted to *Journal of Volcanology and Geothermal Research*. IISN 0377-0273

Balia, R., Criminale, M., Loddo, M., Patella, D., Pecorini, G. and Tramacere, A., 1990: Geophysical Study of the Fordongianus Geothermal area (Sardinia Island, Italy).*Bollettino di Geofisica teorica ed Applicata.* Vol XXXII pp 129-140. ISSN 0006-6729

Balia, R., Criminale, M., Loddo, M., Patella, D., Pecorini, G. and Tramacere A., 1991: A New Geophysical contribution to the study of the Campidano Geothermal area (Sardinia, Italy). *Geothermics* Vol 20 N.3 , pp.147-163. ISSN 0375-6505

Bottari, A., Lo Giudice, E. and Schiamone, D., 1979: Geophysical study of a crustal section across the Straits of Messina. Annali di Geofisica, vol 32, 241-261.

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Loddo, M., Quarto, R., Schiavone, D., Sgrosso, I. and Tramacere, A., 2000: Electric and Magnetotelluric Transect across the Southern Italy Apennine Orogenic Belt. Submitted to *Tectonophysics*.

Loddo, M., Schiamone, D. and Siniscalchi, A., 2000: Generation of synthetic magnetotelluric noisy time series. Proceedings of the VIII Workshop on Geo-Electromagnetism, Maratea, 12-14 Oct. 2000, p. 24-25. Submitted to *Annali di Geofisica*.

Pecorini, G., Balia, R., Criminale, M., Loddo, M., Patella, D. and Tramacere, A., 1988: Studio Geofisico del Bacino del Logudoro (Sardegna) e delle aree circostanti. *Boll. Soc. Geol. Ital*., Vol. 107, pp 547-560. ISSN 0037-8763.

Tramacere, A., Schiamone, D., Veneruso, M., Loddo, M. and Quarto, R., 1998: Prospezione magnetotellurica lungo l'allineamento Tindari-Giardini (Sicilia orientale). XIV Convegno Nazionale del G.N.V., Catania 2-4 marzo 1998.

Tramacere, A., Schiamone, D., Veneruso, M., Loddo, M. and Quarto, R., 1998: Prospezione magnetotellurica lungo l'allineamento Tindari-Giardini (Sicilia orientale). VII Workshop Nazionale di Geoelettromagnetismo, Abano Terme, 7-9 settembre 1998.

Loddo, M., Schiamone, D. and Siniscalchi, A., 2002: Generation of synthetic wide-band electromagnetic time series. *Annals of Geophysics*, 45 (2), 289-301.

PROJECT TITLE

PROJECT AND MANUFACTURING AN AUTOLEVELING VECTORIAL MAGNETOMETER FOR VOLCANIC AREAS MONITORING

Research Unit (RU) Responsible – RU B.1
Name-Position: Antonio Meloni (Researcher Director) and Paolo Palangio (Technological Director)
Affiliation: INGV, Section Roma 2, L'Aquila Observatory

ACTIVITY REPORT–2nd YEAR

RU PARTICIPANTS

Name-Position	Affiliation	man/month
Paolo Palangio Tech. Dir.	INGV	6
Antonio Meloni Res. Dir.	INGV	2
Achille Zirizzotti Technologist	INGV	2

- 2nd YEAR OBJECTIVE

Design and experimentation of an autolevelling tri-axial flux-gate magnetometer prototype for volcanic areas.

- 2nd YEAR RESULTS

In this second phase of magnetometer design and geomagnetic field measurement test, the following were implemented.
A prototype of the autolevelling magnetometer was realised at the geomagnetic observatory of L'Aquila, Italy. The magnetometer consists of a flux gate sensor and its driving electronic circuits and data acquisition system.
The geomagnetic flux gate sensor was designed in order to strictly fit the proposed technical requirements. The magnetometer electronic circuits and the acquisition system were also developed and built at the laboratory of observatory.
The autoleveling magnetometer prototype was tested at the observatory. The following are the measured magnetometer characteristics:

Resolution	50pT
Noise	30 pT/sqr(Hz)
Sensitivity	10 mV/nT
Electronic temperature coefficient	0.007 nT /°C
Sensor temperature coefficient	0.01 nT /°C
Range	1000 nT
Bandwidth	5 Hz
Positioning Error	4"
Sensor Orthogonality Error	0.1°
Compensation Dynamic	10°
Power requirements	12 V 250 mA
Weight and Dimension	26x20x20 cm, 2 Kg

A long period measurement was conducted to compare this magnetometer results with the data observed by the standard geomagnetic acquisition systems of the observatory.
A simulation test of volcanic area measurements was performed in an area not far (40km) from the observatory to test the complete measurement process. In this way, the nine elements of the transformation matrix **A** which transforms geomagnetic field between a station with the autoleveling magnetometer and a reference station with a standard magnetometer (the geomagnetic observatory in this case) was calculated. The non diagonal elements of **A** are shown in fig 1.

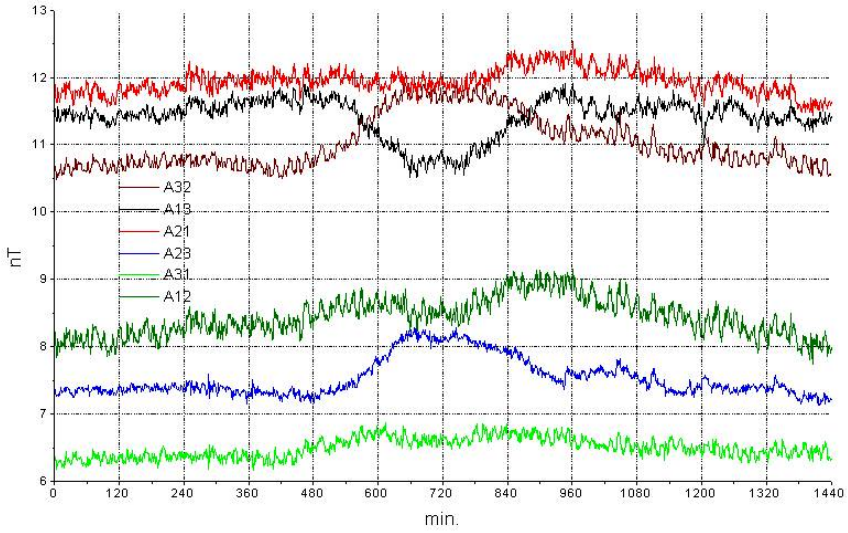

Fig.1

In the 3rd year activities we will make a series of measurements on the volcanic area with this magnetometer for a long period acquisition and in case of relevant results we will be
able to build a series of magnetometer to create a network of magnetometer for monitoring the volcanic areas.

- RESEARCH PRODUCTS

  - A new vectorial magnetometer.

- PUBLICATIONS LIST

PROJECT TITLE

DYNAMIC-STOCHASTIC MODELS AS A TOOL TO IDENTIFY EXTREME EVENTS IN GEOELECTRICAL AND ELECTROMAGNETIC TIME SERIES

Research Unit (RU) Responsible – RU B.2
Name-Position: Vincenzo La penna -Senior Researcher
Affiliation: Institute of Methodologies of Environmental Analysis (IMAA), Area della Ricerca del CNR di Potenza

ACTIVITY REPORT –2nd YEAR

UR PARTICIPANTS

Name-Position	***Affiliation***	***man/month***
Lapenna Vincenzo (senior researcher)	IMAA-CNR	3
Telesca Luciano (researcher.)	IMAA-CNR	4
Sabatino Piscitelli (researcher)	IMAA-CNR	1
Lanfredi Maria (researcher)	IMAA-CNR	1
Balasco Marianna(PhD)	UNIBA/IMAAA-CNR	2
Chianese Domenico(fellowship)	IMAA-CNR	3
Colangelo Gerardo (ext. Coll.)	IMAA-CNR	3

• 2nd YEAR OBJECTIVES

In the frame of the EPOT project the main contribute of this Research Unit concerns the development of innovative methods to identify extreme events in geophysical time series and, in particular, in the analysis of geoelectrical and electromagnetic signals measured in volcanic areas. The main objective for the second year of research activity is the study of the inner dynamics of electromagnetic signals measured in volcanic areas. In particular we search scaling invariance laws (phase C) and estimate the predictability (phase D) of geoelectrical and electromagnetic signals. The algorithm have been designed and validated using the data-base of geophysical time series available at Geophysical Lab of IMAA, in a second step these techniques have been successfully applied to extract quantitative dynamics from time series recorded by means of the magnetic network of Etna volcano.

• 2nd YEAR RESULTS

During the first two phases of the project techniques for the denoising of the time series have been developed and software packages to remove climatic and cultural noises from geophysical time series were designed. After this preliminary activity in the frame of second year of the project we develop advanced statistical techniques to extract quantitative dynamics from geophysical time series.

In particular we focussed our attention to search scaling laws and to obtain an estimate of the predictability of the time series. When the power spectrum density follows a power law form $P(f)=f^{-\alpha}$ there is a presence of long range correlations and the spectral exponent is a measure of the strength of these correlations. Furthermore, the study of scaling laws can give insight in a better comprehension of the physics of the process.

To identify the presence of scaling laws in the geophysical time series we applied the Lomb Periodogram techniques and Detrended Fluctuations Analysis (DFA). The first technique is particularly useful when unevenly sampled time series are considered. The second one was recently proposed by Peng and it avoids spurious detection of correlations that are artefacts of nonstationarity, that often affects experimental data. Such trends have to be well distinguished from the intrinsic fluctuations of the system in order to find correct scaling behaviour of the fluctuations. DFA is an optimal tool for determining the scaling behaviour of data in the presence of possible trends without knowing their origin and shape.

The implemented techniques have been applied and tested on the geoelectrical time series stored in the data-base available at Geophysical Laboratory of IMAAA, that includes more than 200.000 experimental values measured in seismic active areas of Southern Italy.

The analysis has revealed the presence of a scaling law that is a typical fingerprint of process with long memory. Generally, we estimated scaling exponents varying in the interval 1.3-1.9 characterising a Brownian noise that is the integral of white noise, the fluctuations of the electrical signals can be seen as the running sum of a white noise process.

In a second step we develop a new method to investigate the possible correlation between extreme events in electromagnetic time series and seismic or volcanic activity. Generally, the study of the possible correlation between the anomalous pattern in the time series and the occurrence of seismic and/or volcanic events has been approached trying to correlate *one-to-one* the abnormal values with the incoming earthquake. In the frame of the EPOT project we propose a novel approach based on the study of the temporal fluctuations of the scaling exponent, some recent studies indicate the decrease of the α value is a typical fingerprint of clustering phenomena in seismic/volcanic activity.

During the last period of the second year activity, in collaboration with Catania U.O. we applied these algorithms to analyse the time series recorded by the magnetic network of Etna volcano. The first preliminary results allowed us to recognise two scaling laws. At low frequencies the magnetic data are characterised by a flicker noise dynamics, while at highest frequencies we obtaining scaling exponents indicating the presence of persistent long-range correlations.

• RESEARCH PRODUCTS

- n° 4 publications on international journals.
- n° 11 publications on national journals, proceedings of national and international conferences technical reports
- design and implementation of n.3 algorithms for searching scale invariance laws and identifying extreme events in geophysical time series.

• PUBLICATIONS LIST

Cuomo, V., Di Bello, G., Heinecke, J., Lapenna, V., Martinelli, G., Piscitelli, S. and Telesca, L., 2002: Investigating the temporal fluctuations in geoelectrical and geochemical signals jointly measured in a seismic area of southern apennine chain (Italy), *Annali di Geofisica*, Vol. 44, N.2 179-191.

Telesca, L., Cuomo, V., Lapenna, V. and Macchiato, M., 2001: A new approach to investigate the correlation between geoelectrical time fluctuations and earthquakes in a seismic area of southern Italy, *Geophys. Res. Lett.*, vol. 28, n.23, 4375-4378.

Balasco, M., Lapenna, V. and Tedesca, L., 2002: 1/f fluctuations in geoelectrical signals observed in a seismic area of Southern Italy. *Tectonophysics*, 347, 253-268.

Telesca, L., Lapenna, V. and Macchiato, M., 2002: Fluctuation analysis of the hourly time variability in observational geoelectrical signals. *Fluctuation and Noise Letters*, Vol. 2, N.3, 235-242.

PROJECT TITLE

INNOVATIVE METHODOLOGIES FOR THE INTEGRATED INVERSION OF GRAVIMETRIC AND MGNETICA DATA RECORDED IN VOLCANIC AREAS

Research Unit (RU) Responsible – RU B.3
Name-Position: Giuseppe Nunnari- Professor
Affiliation: Dipartimento di Ingegneria Elettrica, Elettronica e dei Sistemi, University of Catania

ACTIVITY REPORT–2nd YEAR

RU PARTICIPANTS

Name - Position	***Affiliation***	***Man/month***
Giuseppe Nunnari – Ass. professor	DEES – Univ. of Catania	2
Maria Angela Pollino	External research collaborator	4
Ingrao Daniele	External research collaborator	2

• 2nd YEAR OBJECTIVES

To develop a tool for integrated inverse modelling of magnetic, gravimetric and ground deformation data in volcanic areas.

• 2nd YEAR RESULTS

During the 2nd year of activity, two main problem were addressed: the direct modelling problem consisting on finding the most appropriate models for generating magnetic, gravimetric and ground deformation data in volcanic areas, and the inverse modelling of magnetic data. The implementation of tools for the generation of synthetic data (direct modelling) is of capital importance for studying the inverse modelling problem. The direct modelling was addressed by considering two different types of volcanic sources: the traditional Mogi's source (Mogi, 1958), whose main advantage is the limited number of parameters involved and the Okada type sources that seems more realistic to interpret eruptive phenomena in volcanic areas such as the Mt. Etna, where eruptions have their origin in dikes opening from a certain depth toward the surface. The direct modelling part of the tool is almost complete. The tool allows computing the effects on ground deformation and magnetic (of piezomagnetic and electrocinetic types) field due to the intrusion of magma in a dyke. For ground deformation the expressions provided by (Okada, 1992) are used while piezomagnetic effects are computed by using the results provided by (Sasai 1991) and (Utsugi et. al. 2000). The electrocinetic effect was implemented by using expressions provided by Murakami (1989) and Fitterman (1979) while the effects on gravity data were implemented by using expressions provided by Ehirishman (1996). Referring to the Mogi's source, the effects on ground deformation were implemented by using expressions provided by (Mogi, 1958) while expressions for computing the piezomagnetic field were provided by (Sasai, 1991). Attempts to solve the direct model problems were carried out by using the Finite Element (FE) modelling approach in order to remove the hypothesis of homogeneity of the half space and to evaluate effects due to the topography of the considered area. It is well known that these are the main restrictions using formulas provided by the authors referenced above. It has experimentally found that considering a layered half-space with different mechanical properties in each layer, tacking also the topographic effects do not give significant difference on the direct modelling solution in terms of ground deformation, and hence in terms of piezomagnetic effects, compared with the analytical solutions. However, this aspect of the direct modelling problem is still under consideration for deeper investigations and the results will be referred in future reports.

The inverse modelling problem was partially completed during the 2nd year of activity. At the present the inversion of ground deformation data and magnetic data have been considered separately in order to study the peculiarities of the two inverse problems. The inversion of integrated data (magnetic, ground deformation and gravimetric data) will be the object of the 3rd year of activity. The two considered inversion problems were formulated following a common scheme based on the use of a Multi-layer perceptron (MLP) neural network. The experimental framework was formulated as follows. A regular grid of 10 by 10 Km centred on the summit volcano area was defined and it was hypothesised that measurements of the magnetic anomalies and ground deformation are performed at the vertices of the grid (direct modelling). Then a MLP neural network was trained to learn the inverse solution associated with a given set of source parameters. The training patterns (examples) were synthetically generated by using the software tool mentioned above. The number of training patterns and the inter-distance between the grid vertices were chanced during the trial in order to characterise the accuracy of the inverse solution in different measuring conditions. Appropriate indexes were defined to give a measure of the accuracy for each parameter of the source (i.e. for the solution of the inverse problem).

The results obtained shows that all the source parameters are correctly identified with a maximum error of about 10% even in presence of a noise level up to 30%.

- RESEARCH PRODUCTS

The results reported above have not been yet published on international journal or conference proceedings but papers are in preparation and a contribution will be presented at the EGS 2003 Conference. Computation codes have been implemented as mentioned in the description of the 2nd year research activity.

- PUBLICATIONS LIST

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PROJECT TITLE

NON-STATIONARY ANALYSIS OF THE GEOMAGNETIC FIELD VARIATIONS FOR THE IDENTIFICATION AND CHARACTERISATION OF VOLCANOMAGNETIC EVENTS.

Research Unit (RU) Responsible – RU B.4
***Name-Position*:: ** Prof. Maurizio Fedi, Full Professor
Affiliation: Science of the Earth Department, University "Federico II" , Naples

ACTIVITY REPORT – 2 nd YEAR

UR PARTECIPANTS

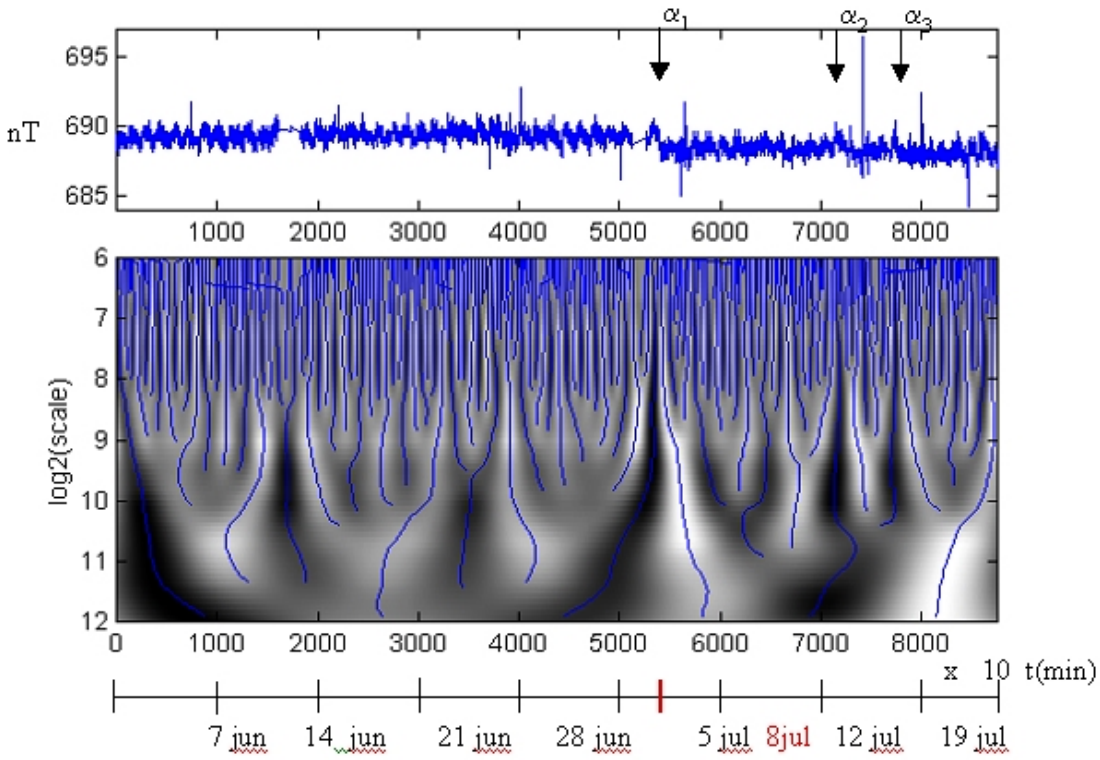
Name	***Position***	***Affiliation***	***Man/month***
Maurizio Fedi	Full Professor	University "Federico II" Naples	5
Giovanni Florio	University Researcher	University "Federico II" Naples	4
Angelo De Santis	First Researcher	National Geophysical and Volcanological Institute	3
Tatiana Quarta	University Researcher	University of Lecce	3
MAuro La Manna	PhD student	University "Federico II" Naples	3
Rita Primiceri	PhD student	University of Lecce	3
Francesco Palmieri	Full Professor	Second University of Naples	2
Federico Cella	University Researcher	University of Calabria Cosenza	2

- 2nd YEAR OBJECTIVES

Definition and application of methods based on time-frequency analysis by means of the Continuous Wavelet Transform (CWT) for the identification and the characterisation of events of volcanomagnetic character by a non stationary analysis of data from magnetometric surveillance networks.

- 2nd YEAR Results

During the second year of activity, we developed an innovative method for the identification and the characterisation of volcanomagnetic events. This method, called Continuous Wavelet Transform Singularity Analysis (CWTSA), allows the identification of rapid changes in geomagnetic time sequences, which may be related to significant events. Generally, geomagnetic signals are non-stationary and contain rapid changes, usually steps, jerks etc. For this reason, the CWTSA was applied to detect the singularities present in the time geomagnetic series. Some theorems [Mallat and Hwang, 1992] prove that the wavelet transform is an optimal tool to define the local regularity of a function, which will be the main object of our research next year. The wavelet transform modulus maxima lines (WTMML) are the lines interconnecting the maxima of the modulus of the wavelet transform within the cone of influence and across the time-scale plane. They emanate from the abscissas where the singularities are located. The partitioning of the time-scale plain with WTMML provides an efficient measurement procedure of the local Holder exponents associated with singularities, through the slope of the WTMML at small scales.
CWTSA has been implemented to detect "singular" events (or sudden signal variations) that could be connected to geomagnetic variations linked to seismic and volcanic events. This type of analysis is applied to a test case. In the figure an example of CWTSA applied to the difference of geomagnetic time series recorded along San Andreas fault during a seismic event of July 8, 1986 (North Palm Springs earthquake) is shown. The geomagnetic time series analysed, related to a seismic event, were from Dr. Malcolm Johnston of USGS.
In this figure the CWTSA was applied to the difference (upper diagram) of the time series recorded from June 1 to July 31 1986 in two stations, the first located in the epicentral area while others is positioned more distant. Many cones of influence are well detected in the time-scale plane (low diagram), relative to particular days. The most evident cones are three; the first one around the July 8 (α_1), the other two at July, 21 (α_2) and 27 (α_3) respectively. According to the singularity analysis, we observe a sharp variation of the signal (singularity) at the point of abscissa t_0, where the cones of influence begins. It is important to note that the relative event to the July 8 well corresponds to the day of the earthquake. We also observe at least others two events, corresponding to the July 21 and 27. Unfortunately, we do not have other information about these possible seismic events. In this year, we are working to develop another technique of analysis (Regularity Analysis) to characterize the events detected by CWTSA and TVANS techniques. It is based on multifractal approach of the geomagnetic signals. It provides a method to compute the singularity spectrum of the signals vs time by a sliding-window. Actually, we are implementing and testing this technique to synthetical case.



- RESEARCH PRODUCTS

  - 1 publication
  - Presentation to the European Geophysical Society XXVII General Assembley, Nice, France, 21-26 Aprile 2002. Title of discussion: " Non stationary analysis of geomagnetic time sequences ".

- PUBLICATIONS LIST

Fedi, M., La Manna, M. and Palmieri, F., 2002: Non stationary analysis of geomagnetic time sequences from Mt. Etna and North Palm Springs earthquake, *Journal of Geophysical Reasearch*, submitted.

Fedi, M., Goncalves, P., Johnston, M. and La Manna, M, 2002: The identification of seismo- and volcano-magnetic events using non-stationary analysis of geomagnetic field variations. In *Geophysical Research Abstracts*, 27th EGS General Assembly, Vol. 4.

PROJECT TITLE

HARDWARE AND SOFTWARE IMPROVEMENTS IN GRAVITY MONITORING OF ACTIVE VOLCANOES

Research Unit (RU) Responsible – RU C.1
Name-Position: Gennaro Budetta - **Research manager**
Affiliation: INGV - Sezione di Catania - piazza Roma 2 - 95123 Catania

ACTIVITY REPORT – 2nd YEAR

RU PARTICIPANTS

NAME-POSITION	***Affiliation***	***Man/Month***
Gennaro Budetta – research manager	INGV - Catania	2
Bruno Andò – researcher	DEES - University of Catania	2
Daniele Carbone - researcher	INGV - Catania	3
Filippo Greco - researcher	INGV - Catania	2

- 2nd YEAR OBJECTIVES

Continuous gravity observations by spring gravimeters as a tool to monitor active volcanoes have not developed as quickly as other geophysical techniques due to the difficulty in achieving acceptable signal-to-noise ratios at sites where the conditions are far from the clean, ideal ones found in the laboratory.

This project is aimed at improving the possibilities of continuous gravity observation at active volcanoes on the grounds of the experience achieved and data acquired since 1996, when three experimental stations were first installed at Mt Etna. The tasks for the second year of this project are:

1. Designing software to quickly analyse long gravity data-sequences;
2. Modelling how the meter output depends on the interfering meteorological signals;
3. Recognition and study of the anomalous gravity changes.

- 2nd YEAR RESULTS

Task 1 - Designing software to quickly analyse long gravity data-sequences

Since continuous gravity measurements have scarcely been made in the past, it is still quite hard to recognize and interpret the useful (i.e. volcano-related) pieces of information within the gravity sequences acquired at remote stations. To make this task easier we have designed an advanced software package under the LabVIEW programming environment which allows the large data sets coming from the remote stations to be analysed quickly and with a high level of automation. Since this software is quite easy to implement, it allows changes in the continuously

running array to be accommodated on one hand, and can be used to handle data from other similar arrays on the other.

During the first year the general architecture of this software package was designed. Great care was taken in designing the program interface to make it usable even by the inexperienced operator. Also all the controls needed to suitably reduce the data were implemented.

During the second year all the virtual instruments already developed have been improved to assess an even quicker reduction of rough data coming from the remote Etna stations and to allow a quasi-real-time visualization of the reduced sequences which is vital for volcano monitoring purposes. In addition, some features of the software developed have been improved to allow a better manipulation of the gravity series, namely:

i) new FIR digital filters, which better suit the need for extracting given components of the signal, have been designed and implemented into the program;

ii) new operators to perform operation in the frequency domain have been implemented (power spectrum, amplitude spectrum, Cross Power Spectrum).

Task 2 - Modelling how the meter output depends on the interfering meteorological signals

Meteorological perturbations (temperature, pressure, humidity) affect continuous gravity sequences and give rise to a pseudo-signal which is often stronger than the useful one. To remove the effect of these perturbations is not easy given that the transfer functions are frequency-dependent and are different for each gravimeter employed. During the first year of the present project some attempts to model the effect of the meteorological parameters through both linear and non-linear (Neuro-Fuzzy) algorithms were accomplished.

During the second year new experiments were performed to optimise the algorithms already developed. In particular, a Neuro-Fuzzy algorithm, which had already proved to accomplish the required task satisfactorily, was tested over a data set from three gravimeters which worked continuously for about 50 days at a site far away from active zones, where changes due to actual fluctuation of the gravity field are expected to be within a few microGal. After accomplishing the reduction of the gravity series, residuals were within a few microGal peak-to-peak, thus confirming the capabilities of the Neuro-Fuzzy algorithm under test to perform the required task satisfactorily.

Task 3 – Recognition and study of the anomalous gravity changes

Continuous gravity sequences acquired on volcanoes can be split into two main components: i) anomalies linked to the activity of the volcano itself (useful signal) and ii) signal due to tides, instrumental and meteorological effects (assumed as noise). Thus, the improvement of the signal/noise ratio is fundamental to recognize the anomalies due to volcanic activity within a gravity sequence. To date, to achieve a better signal/noise ratio we have: a) re-calculated the parameters of the main tidal components using the longer sequences available to improve the tidal gravity models for Etna; b) improved the electronics of each gravity station to reduce instrumental effects; c) insulated each station from the thermal standpoint through passive (polystyrene boxes) and active (thermosetting systems – still under development) devices (task 1 – 1st year of this project); tested various algorithms to model the effect of meteorological perturbations on the gravity signal (see above – task 2). During the second year the overall significance of the available sequences has improved given they are longer and encompass two eruptions (the July-August 2001 eruption and the one begun in October 2002 and still continuing). Accordingly we were able to start a new phase consisting in the assessment of the volcano-related gravity anomalies. Recognizing these anomalies is trivial when paroxysmal events take place, but can be very difficult during ordinary phases of the activity. However, having at our disposal long sequences with many events most likely due to the volcanic activity, we should be able to achieve satisfactory results. In this preliminary stage the following steps have been taken:

- selection of events according to their correlation to the volcanic activity;
- volcanological consistency check of the selected events;
- preliminary attempts for characterizing the selected events;
- testing new algorithms for a further improvement of the signal/noise ratio.

- RESEARCH PRODUCTS

  - 3 articles published in international journals;
  - 3 article published in national journals, proceedings, technical reports;
  - 3 presentations at international meetings;
  - 2 presentations at national meetings;
  - LabView virtual instruments to quickly analyse long gravity data-sequences.

- PUBLICATIONS LIST

Andò, B. and Carbone, D., 2001: A Methodology for Reducing the Signal from a Continuously Recording Gravity Meter for the Effect of Meteorological Parameters. *IEEE Transactions on Instrumentation and Measurement,* 50 (5), 1248-1254.

Carbone, D., Budetta, G. and Greco, F., Possible mechanisms of magma redistribution under Mt. Etna during the 1994-1999 period detected through microgravity measurements. Geoph. J. Int*., in press.*

Carbone, D., Budetta, G., Greco, F. and Rymer, H., 2002: Combined discrete and continuous gravity observations at Mt. Etna. *J. Volcanol. Geoth. Res.*, in press.

Budetta, G., Carbone, D. and Greco, F., 2001: Microgravity observations at Mt. Etna during the 2001 eruption*. Atti del Convegno Scientifico annuale del Gruppo Nazionale per la Vulcanologia (GNV). Roma, 9-11 Ottobre 2001,* 226-227.

Budetta, G., Carbone, D. and Greco F., 2002: Il dispositivo di monitoraggio gravimetrico dell'Etna. *Atti del XXI Convegno Nazionale del Gruppo Nazionale di Geofisica della Terra Solida (GNGTS). Roma, 19-21 Novembre 2002*, 245-247.

Budetta, G., Carbone, D. and Greco, F., 2002: Installazione ad alta quota di una stazione gravimetrica in telemetria: applicazioni all'Etna. *Quaderni di Geofisica*, n. 23, 8 pp.

Carbone, D., Budetta, G., Greco, F. and Rymer, H., 2001: Combined discrete and continuous gravity observation at Mt Etna. *The EUG XI, Strasbourg - 8th-12th April 2001.*

Budetta, G., Carbone, D. and Greco, F., 2001: Microgravity observations at Mount Etna during the 2001 eruption. *EGS XXVII General Assembly, Nice, France, 21-26 April 2002.*

Carbone, D., Budetta, G. and Greco, F., 2002: Microgravity changes associated with the July – August 2001 Etna eruption. *AGU 2002 Fall meeting in San Francisco, 6-10 December 2002*.

Budetta, G., Andò B., Carbone, D. and Greco F., 2001: Hardware and software improvements in gravity monitoring of active volcanoes. Convegno Scientifico annuale del Gruppo Nazionale per la Vulcanologia (GNV). Roma, 9-11 Ottobre 2001, 17-18.

Budetta, G., Carbone, D. and Greco, F., 2001: Microgravity observations on Mt. Etna during the 2001 eruption. *XX Convegno Nazionale del Gruppo Nazionale di Geofisica della Terra Solida (GNGTS). Roma, 6-8 Novembre 2001*.

PROJECT TITLE

APPLICATION OF NON-CONVENTIONAL TECHNIQUES FOR MAGNETIC MONITORING OF ACTIVE VOLCANOES

Research Unit (RU) Responsible – RU C.2
Name-Position: Ciro Del Negro – Researcher
Affiliation: Sezione di Catania, INGV – Piazza Roma 2 – 95123 Catania

ACTIVITY REPORT – 2st YEAR

RU PARTICIPANTS

NAME-POSITION	***Affiliation***	***Man/month***
Ciro Del Negro – Senior researcher	Sezione di Catania-INGV	6
Napoli Rosalba – Researcher	Sezione di Catania-INGV	6
Alfio Amantia – Technician	Sezione di Catania-INGV	2
Gilda Correnti – Ph.D. student	University of Catania & INGV	9
Antonino Sicali - Technician	Sezione di Catania-INGV	6
Annamaria Vicari - Ph.D. student	University of Catania-INGV	3

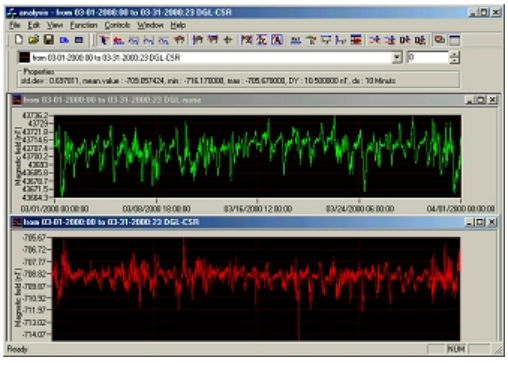
- 2nd YEAR OBJECTIVES

The aim of the project is improving the investigative capabilities of the magnetic method, in its possible applications in active volcanic areas. The task for the second year of this project is application of non conventional techniques to detect and evaluate magnetic transients. Then, a software, has been designed, to reduce the delay between observation and interpretation of geomagnetic data-sequences.

- 2nd YEAR RESULTS

MADAP: MAgnetic DAta Processing

We have developed a code, called MADAP, which allows a high skill level to be achieved by the operator for applying different analysis techniques. The code was designed in C++ language and includes a powerful, comprehensive package of analysis routines for reducing magnetic disturbances.



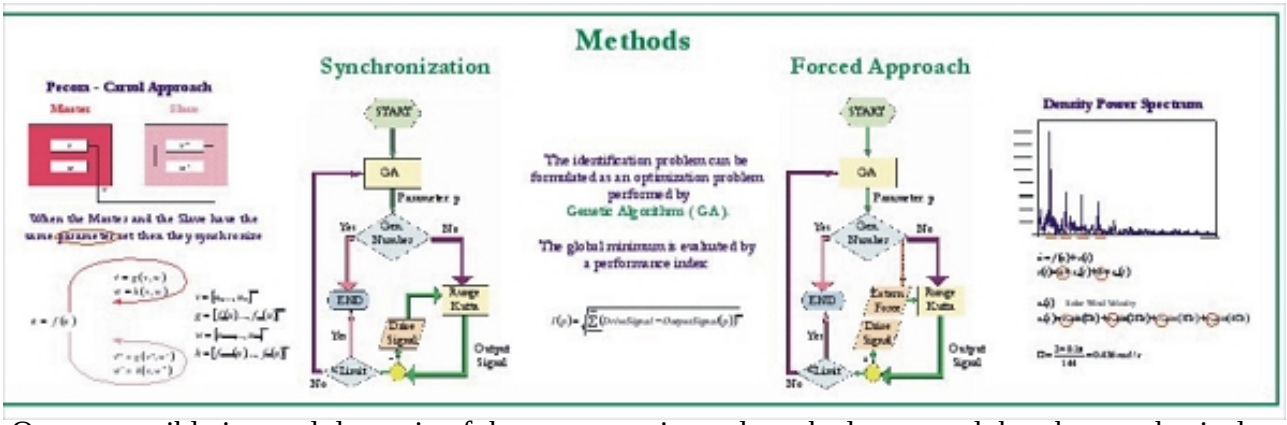
- The classical differential technique was implemented with the option to verify the synchronization between signals recorded at different stations by cross-correlation function. We also included Steppe's (1979) method to find differences between a given station and a weighted linear combination of the remaining stations in a total field array, where the weights are determined by linear regression.

- A more detailed data analysis was added by employing the method developed by Poehls and Jackson (1978), which relates the vector field at the reference site to the total field at the observation sites by empirical transfer functions to filter out residual variations caused by transitory fields. This method is effective in reducing the residuals associated with diurnal variations, thus allowing volcanomagnetic events, even shorter than a few days duration, to be detected.
- To distinguish between transients of volcanomagnetic origin and transients generated by strong variations in the external transitory magnetic field, we implemented the method devised by Del Negro and Ferrucci (2000), which takes into account the correlation between the measurements at two stations. This method is useful when the observation sites are relatively few.

- A module for the joint time-frequency analysis, a signal processing technique in which signals are analyzed in both the time and frequency domain simultaneously, has been implemented. This module uses a rather sophisticated time-dependent spectrum analysis allowing to examine the instantaneous spectrum of a signal and discover how it changes over time, thus providing a more complete representation of the signal and consequently a better understanding of its nature.
- To reduce the changes in the difference fields due to contrasting responses at magnetometer sites, we are emplementing methods of predictive filtering, with the filters giving the relative responses between sites. The predictive analysis allows some time-intervals to be identified where important statistical variations of the signal are present. These zones are also called non-stationary zones. Considering that the phenomenology of the process is time-variant, a non-stationary approach is more useful to describe the physical processes tied to volcanic dynamics. For this reason we have also been implementing an adaptive type approach (Currenti et al., 2002).
-To remove effect of temperature from geomagnetic total intensity measurements, we use the method proposed by Utada et al. (2000). In this technique the features of annual variations can be quantitatively explained by analyzing field data and examining the magnetic properties of rock samples from Mt. Etna. By applying this method, the annual variations can be removed with a simple linear one-coefficient filter.

Complexity into geomagnetic signals

There is the notion of developing some new methods as a valid alternative for the characterization and the growth of complex system models. These methods are based on chaotic analysis. The first step is to consider the complex geophysical systems, as autonomous systems, namely systems that starting from an initial condition evolve spontaneously. Supposing, therefore, some chaotic structures as the base model for the description of the geophysical systems, and using some techniques, non sensitive to the initial conditions, as for example the synchronization, we had tried to determine the internal dynamics of the geomagnetic time series. In the synchronization technique, we establish that two dynamic systems follow the same trajectory, starting from different initial conditions. The dynamic system whose parameters have to be estimated is considered as master system and one of its state variables is used to drive an identical slave system. The slave system responds to the driving signal following a state trajectory that depends on this input signal and on its parameters. The difference between the master's state variable and its corresponding slave's state variable is used to define a performance index. The master and the slave will synchronize if they have identical parameters. The goodness of the synchronization will be evaluated by choosing a suitable performance index.



Once a possible internal dynamic of the system estimated, we had supposed that the geophysical systems can be modeled as nonautonomous systems, that is systems which evolve under the influence of some external deterministic forces. A fundamental point is to understand for our geophysical system, what the major factors of influence are. In such a way, we make an estimate of a possible external dynamic of the systems. In either case considered (autonomous and non autonomous model), our identification problem can be formulated as an optimization problem.

Therefore, we take advantage of a genetic algorithm (GA) which performs a search of an optimal solution to a problem by minimizing (or maximizing) the performance index. The advantage compared to other tools of optimal research, as for example gradient technique, is that GA never falls in a local minimum (or maximum).

- RESEARCH PRODUCTS
  - n. 8 publications on international journals
  - n. 4 presentations to international meetings (1 at 2002 EGS Assembly in Nice; 2 at 2002 MEEMSV Workshop in Moscow; 1 at 2002 AGU Fall Meeting in San Francisco)
  - n. 2 presentations to national meetings (2002 GNGTS in Rome)
  - n. 2 software packages (VMM and MADAP)

- PUBLICATIONS LIST

Del Negro C., Napoli R., (2002). Ground and marine magnetic surveys of the lower eastern flank of Etna volcano (Italy), J. Volcanol. Geotherm. Res. 114/3-4, 357-372.

Del Negro C., Napoli R, Sicali A. (2002). Automated system for magnetic monitoring of active volcanoes, Bulletin of Volcanology, 64, 94-99.

Del Negro C., Ferrucci, F., Napoli R., (2002). Marine magnetic investigation of the submarine base of Mt. Etna and Iblei mountains, Annals of Geophysics, 45, 2, 361-374.

Del Negro, C. and Currenti, G. (2002). Volcanomagnetic Signals Associated with the 2001 Flank Eruption of Mt. Etna (Italy), Geophys. Res. Lett., 2002GL015481, accettato per la stampa.

Del Negro C., Napoli R., (2002). Magnetic field monitoring at Mt. Etna during the last 20 years, In "Etna Volcano Laboratory" (Eds. S. Calvari, A. Bonaccorso, M. Coltelli, C. Del Negro and S. Falsaperla), AGU Geophysical Monograph series, in print.

Currenti, G., Del Negro, C., Fortuna, L., Vicari, A. (2002). Nonlinear Identification of Complex Geomagnetic Models: An Innovative Approach, Journal NPCS, in print.

Incoronato, A. and Del Negro, C. (2002). Magnetic stratigraphy procedures at Etna. In "Etna Volcano Laboratory" (Eds. S. Calvari, A. Bonaccorso, M. Coltelli, C. Del Negro and S. Falsaperla), AGU Geophysical Monograph series, submitted.

Mauriello, P., Patella, D., Petrillo, Z., Siniscalchi, A., Iuliano, T. and Del Negro, C. (2002). A 3D geophysical model of the Mt.Etna volcanic area. In "Etna Volcano Laboratory" (Eds. S. Calvari, A. Bonaccorso, M. Coltelli, C. Del Negro and S. Falsaperla), AGU Geophysical Monograph series, submitted.

PROJECT TITLE

A NEW MULTI-RESOLUTION, INTEGRATED SYSTEM FOR THE INTELLIGENT PROCESSING OF DATA RECORDED IN ACTIVE VOLCANIC AREAS

Research Unit (RU) Responsible – RU C.3
Luigi Fortuna
Full Professor
Dipartimento di Ingegneria Elettrica, Elettronica e Sistemistica

ACTIVITY REPORT–2nd YEAR

RU PARTICIPANTS

NAME-POSITION	***Affiliation***	***Man/month***
Fortuna Luigi - Full Professor	DIEES – University of Catania	2 mesi
Andò Bruno– Associate Professor	DIEES – University of Catania	3 mesi
Graziani Salvatore - Associate Professor	DIEES – University of Catania	2 mesi
Rizzo Alessandro - Researcher	DEE – Politecnico of Bari	3 mesi
Claudia Bonomo – Ph.D. student	DIEES – University of Catania	6 mesi

- 2nd YEAR OBJECTIVES

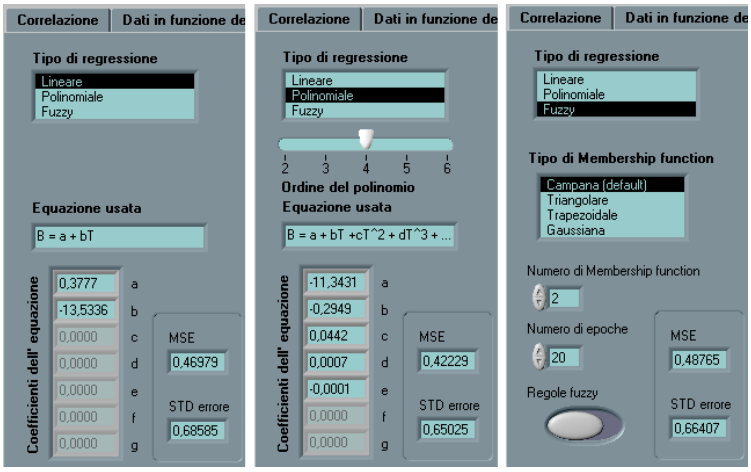
The aim of the project is the development of a new architecture, devoted to the automatic elaboration of information recorded in volcanic active areas. In particular the architecture is based on a multi-resolution, integrated approach, organized in a complex computing structure. The task of the second year is the realization of B_j blocks devoted to the elaboration of linguistic information. Moreover, a research activity started, at Tecnolab, about an innovative deformation sensor.

- 2nd YEAR RESULTS

Multi-approach analysis

Data collected from the magnetic monitoring network of Etna volcano, furnished by researchers of the RU C.2, are analysed in a very short time scale-sampling interval.

In order to build a modular system, some tools have been implemented, utilizing the capabilities of Matlab and LabVIEW™. These tools can investigate different geophysical signals, and allow the user to interactively analyse the acquired data and to compare the corresponding results. Different strategies have been adopted to allow the effective elaboration of data of different nature. In particular both neural and neuro-fuzzy approach have been taken into account to face with the complexity of the considered phenomena. Regardless of the adopted strategy a black box approach has been used and the items of input output variable choice, data filtering, model structure choice, model order choice, parameter estimation, and model validation have been addressed.



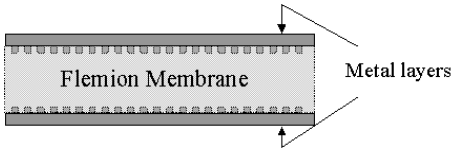
The tools for the automatic solution of the above mentioned tasks have been developed both for non-linear polynomial, neural, and neuro-fuzzy models.

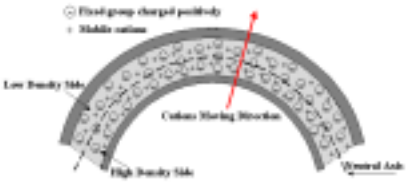
Such a characterization has to be considered as a preliminary approach. In fact, in accordance with the proposed activity, in the third year will focus on estimation of:

1. quality of the obtained models;
2. accuracy of results suggested by the developed system.

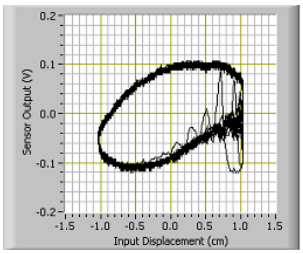
Study, Fabrication and Applications of New Materials for Detecting Deformations

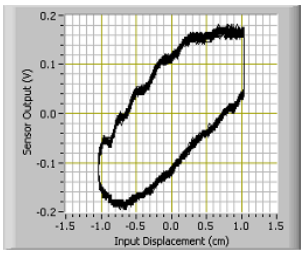
Ionic Polymer Metal Composites (IPMCs) are innovative materials obtained by deposition of a metal on a ionic polymer membrane. IPMCs bend, if an electric field is applied along their thickness, and vice versa generate a voltage when mechanically deformed. Hence, IPMCs can be used to build actuators and sensors as well. They are of interest because the voltage necessary to activate the bending is much lower then the voltage required to other moving actuators (few volts against e.g. hundreds of volts for piezoelectric materials). The IPMC strip used for our analysis is made by the ionic polymer Flemion™ (by Asahi Glass) with gold deposed on both sides. Its typical thickness is about 200 μm.





A measurement survey has been executed on a sample of IPMC (38 mm long by 6 mm large). The experimental setup is composed by a system that imposes a displacement to the membrane tip and a circuit to amplify the output voltage to be recorded. One thousand samples per second have been acquired for each frequency and each acquisition lasted ten seconds, i.e. ten thousand samples for each acquisition survey. The range of the tested frequencies spans from 1 Hz to 10 Hz, with steps of 0.5 Hz approximately. Recorded data have been analysed by using LabVIEW software. Plotting the voltage signal versus the imposed displacement (Input/Output Diagrams) a non-linear relationship has been observed. The first results show a good sensorial behaviour of the material: the voltage generated across an IPMC strip is proportional to the forced displacement and it depends also from the exciting frequency. From now the work will regard the research of the law that links the input displacement (amplitude and frequency) to the output voltage in order to completely define the sensor characteristic.





- RESEARCH PRODUCTS
  - n. 1 publication on international journal;
  - n. 2 presentations at international meetings (10th International Workshop NDCS in Minsk; IEEE CAS Society)

- PUBLICATION LIST

Bonomo, C., Del Negro, C., Fortuna, L., Graziani, S. (2002). Characterization of an IPMC strip's sensorial properties: preliminary results, IEEE CAS Society, submitted.

Currenti, G., Del Negro, C., Fortuna, L., Vicari, A. (2002). Nonlinear Identification of Complex Geomagnetic Models: An Innovative Approach, Journal NPCS, in print.