PAROXYSM

PERICOLO VULCANI
La ricerca scientifica per la mitigazione del rischio vulcanico in Italia
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PROTEZIONE CIVILE NAZIONALE

INGV

Activities of RU7
Seismological analysis of paroxysms and effusive eruptions at Stromboli

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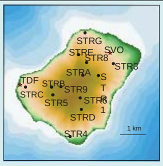
Paroxsysm - Definition of expected precursors for major explosions, paroxysms and effusive eruptions at Stromboli volcano

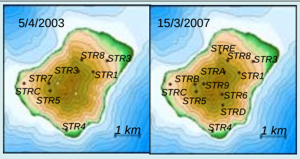
Task 1: Modeling of volcanic processes in the plumbing system.
Task 2: Precursors of paroxysms and major explosions.
Task 3: Precursors of effusive eruptions.

Activity of our Research Unit for Task 1 (Modeling of volcanic processes in the plumbing system)

The two most recent paroxysms at Stromboli have been preceeded by Ultra-Long-Period (ULP) seismic signals recorded by broadband seismic stations (in 2003) and also by dilatometers (in 2007). The overall features of these signals indicates an increasing pressurization of the volcanic conduit preceding the explosions, leading to a progressive quasi-static deformation of the volcano edifice. We have modeled these signals using a finite-element approach and inverted them using point source moment tensor inversion techniques. The retrieved source positions are locate very close to the source of Very-Long-Period (VLP) events commonly associated with the Strombolian explosions (Martini et al., 2007). The source functions suggests an almost exponential increase of the pressure in the minutes preceeding these explosions.



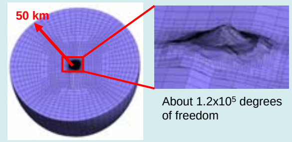
The INGV broadband seismic network of Stromboli
● 13 broadband stations
★ 2 dilatometers



8 broadband stations 300 s of recordings

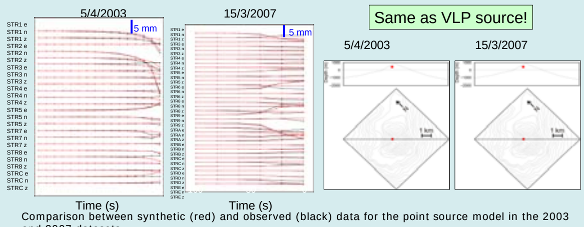
12 broadband stations 100 s of recordings

Stations used for the inversion of 2003 and 2007 seismic signals



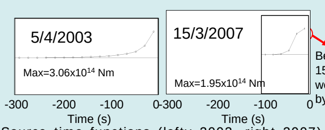
PAROXYSM 1.4 : C++ parallel code based on deal.II libraries

Finite element grid used for computing synthetic deformations

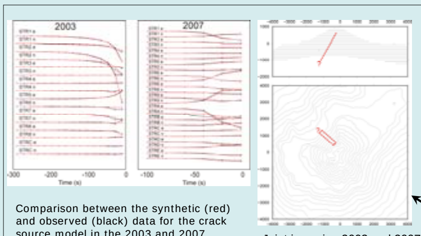


Comparison between synthetic (red) and observed (black) data for the point source model in the 2003 and 2007 datasets

2 orders of magnitude stronger than Strombolian explosions



Source time functions (lefty 2003, right 2007). The S.F. of the 2007 paroxysm differs slightly since in the last part it shows a bent indicating almost stationary conditions for at least 10 s before the explosion. This can be justified considering that the summit craters in the early phase of the 2007 eruption created an obstruction of the conduit.



Comparison between the synthetic (red) and observed (black) data for the crack source model in the 2003 and 2007 datasets. On the right the retrieved source geometry.

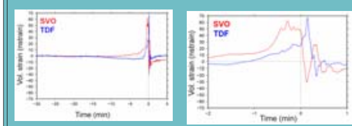
Joint inversion 2003 and 2007 Simplex algorithm

We have then performed a similar analysis using an extended source model with a crack geometry. The inversion has been performed using a non-linear approach based on the Simplex algorithm. The fit, compared with the point source model is greatly improved. The source geometry consists in an inclined crack (dip 70°, azimuth 40°N) with a width of about 250 m and a length higher or equal to 1500 m. For the length it was possible to put only a lower bound since the available dataset does not allow a further constrain.
The geometry is compatible with the results of Chouet et al. (2008) which retrieved the shallow conduit geometry using VLP signals of ordinary explosions.

Crack parameters: Azimuth: 40°; Dip: 70°; Lenght: > 1500m; Width: 250 m

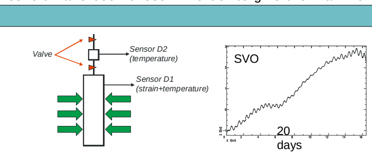
Activity of our Research Unit for Task 2 (Precursors of paroxysms and major explosions)

We have developed a method for the rapid real-time detection of ULP precursors of paroxysms using both dilatometer and broadband signals.
At the end of 2006 two dilatometers were deployed on Stromboli at two opposite edge of the island: SVO (S. Vincenzo Osservatorio) and TDF (Timpone del Fuoco). The dilatometers are sensitive to volumetric strains of the order of 10^{-9} (few nanostrains). The spectrum of the dilatometric signal is dominated by tide components and by short period oscillation induced by atmospheric pressure disturbances. The removal of tide components from the strain signal has revealed to be a hard task because of the superposition of earth, sea and groundwater tides. We have focused our attention on procedures aimed at the real-time removal of all the tide signals. Luckily there is a net separation between the spectral peaks of the tide components and the ULP precursory signals, so an efficient solution is to adopt IIR (Infinite Impulse Response) filters to remove signals having period longer than few hours. The remaining source of noise are the atmospheric pressure transients with a period of few minutes, and so overlapped to the ULP signal band. Sensitive microbarometers are collocated with dilatometers and their signals are acquired with the same sampling rate of dilatometric signals (50 Hz). Using statistical analysis we computed a correlation coefficient between high frequency (>1200 s) pressure transient and the dilatometric signal. This information is used to subtract from the dilatometer signals spurious transients that can lead to false triggers. After the subtraction of the pressure component the signal is analyzed using a simple absolute trigger mechanism. If it exceed a fixed threshold for at least 15 s then the trigger is activated and sent to the Early Warning Web Interface (EWWI) system. The threshold have been chosen in order to give the maximum warning time but avoiding false triggers due to major explosions and teleseisms.



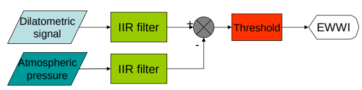
The 2007 paroxysm. The time is relative to the blast.

By using our method the signal of SVO would have provided a warning of about 100 s, while the signals of TDF about 55 s before the blast.



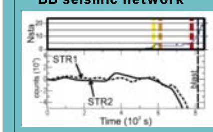
A simplified scheme of a dilatometer and on the right an example 20 days recording at SVO showing tidal oscillations and a long term trend due to both strain and pressure.

Dilatometers

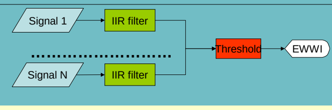


Scheme of the real-time processing of dilatometric data.
The IIR filter are band-pass between 1200 and 10 s.

BB seismic network

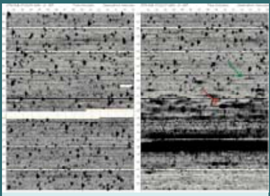


After D'Auria et al. (2006).



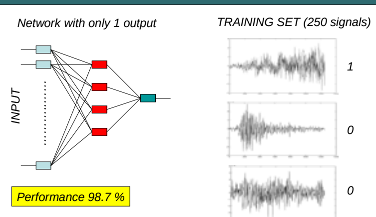
A procedure similar to that used for dilatometers signals has been applied to the broadband signals in order to use them for the early warning of paroxysms. This system would have provided a warning of about 45 s for the 2003 and of about 20s for the 2007 paroxysm.

Activity of our Research Unit for Task 3 (Precursors of effusive eruptions)

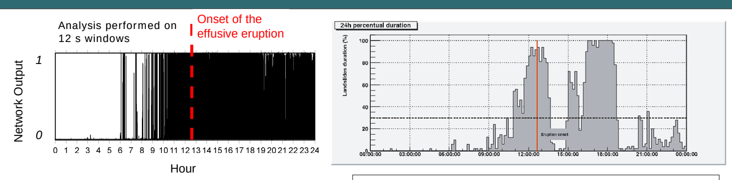


Seismograms of 26 (left) and 27 (right) Feb. 2007. The green arrow on 27 indicates the first recognized landslide at 08:57, while the red arrow indicates the onset of the effusive eruption

The effusive eruption of 27th February 2007 was characterized by a significative short term precursor: the occurrence and the increase of landslide related seismic signals. In the morning of 27/02/2007 it was first noticed the occurrence of landslides at 08:57 UT. This was followed by a progressive increase which culminated with the opening of the eruptive vents. we have developed, tested and applied a technique, based on neural network analysis, for the automatic detection of landslide seismic signals, especially devoted to the recognition of critical situation such as an approximating effusive eruption. The neural network has been designed in order to discriminate window of seismogram recognizing the presence or not of a landslide signal in it. Previous results (Esposito et al., 2006) have driven the choice of the network architecture. The structure of the network consists in three layers of neurons: the input, the hidden and the output. The input layer receives the seismogram to analyze in a parametrized format. The parametrization converts the raw seismogram in a vector of 72 elements containing information about the shape of the seismogram envelope (24 coefficients) and on the spectral content (48 coefficients). The output consists in a single neuron whose output value (ranging from 0 to 1) indicates if the analyzed seismogram chunk contains or not a landslide. The network has been trained over a dataset consisting in 350 manually picked and classified signals and tested on a dataset of 230 signals showing an average performance in the recognition of about 98.7%.



On the left a scheme with the neural network structure, on the right an example of signals used for training. The first is a landslide, the others are an explosion-quake and volcanic tremor. The expected output (0,1) is indicated on the right.



The left panel represents the raw output of the neural network, while the right panel represents the landslide index computed on 10 minutes window. The red lines mark the onset of the eruption. The orange line in the right panel marks the warning with a threshold of 30% and a minimum duration of 30 min.

A value higher than 30% is a pre-warning
Peristence above 30% for more than 30 min is warning
27/2/2007: warning about 110 minutes before the eruption

Landslide index

$$I = \frac{\text{Windows with output} > 0.95}{\text{Total number of windows}} \text{X100}$$

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•Esposito A. M., F. Giudicepietro, S. Scarpetta, L. D'Auria, M. Marinaro, and M. Martini (2006), Automatic Discrimination among Landslide, Explosion-Quake, and Microtremor Seismic Signals at Stromboli Volcano using Neural Networks, Bulletin of the Seismological Society of America, Vol. 96, No. 4, pp. 1–, August 2006, doi: 10.1785/0120050097
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