Scientific community and civil protection synergy during the Stromboli 2002-03 eruption

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Abstract

The eruption of Stromboli 2002-03, thanks to its complex scenario (*flank instability, tsunami, necessity to rapidly upgrade monitoring networks*) has provided an important opportunity to verify the response of the national system of civil protection to volcanic emergencies. In particular, it has tested and validated the model of collaboration, in use by Italian law, between the Department of Civil Protection and the National Institute of Geophysics and Volcanology. This synergy has enabled a better understanding and ability to tackle the eruptive crisis from its first stages, as well as implement monitoring systems both dependably and swiftly. In this work, the numerous first monitoring tasks carried out during the critical initial stages of the eruption are described, and the activities and planned action are reported over the course of the eruption that has made Stromboli one of the best monitored volcanoes not only in Italy but throughout the world.

1. Introduction

In Italy, the national service for the emergency management, known as Civil Protection, was instituted with the aim of protecting the integrity of life, heritage, inhabited settlements and the environment from damage or the threat of damage caused by natural calamities, catastrophes or other disastrous events (State decree n. 225, 1992). This national service is under the control of the Presidency of the Council of Ministers that promotes and coordinates the activities of the administration of the State and all government bodies. To carry out these objectives, the Presidency of the Council relies upon the Department of Civil Protection, *Dipartimento di Protezione Civile* (DPC), which is thus responsible for coordinating all the activities carried out in an emergency.

Until the end of the 1990s, there were various research groups in Italy that maintained permanent seismic monitoring systems in different areas of the country and at the active Italian volcanoes. The National Institute of Geophysics and Volcanology, *Istituto Nazionale di Geofisica e Vulcanologia* (INGV) was founded in 1999 (Decree n. 381, 1999) in order to officially carry out seismic and volcanic surveillance of the national territory and to coordinate regional and local seismic networks. A number already existing research and monitoring institutions, such as the National Institute of Geophysics (Rome), the Vesuvian Observatory (Naples), and the National Research Council Institutes of Volcanology (Catania), Geochemistry (Palermo) and Seismic Risk (Milan) were then united within the INGV. The INGV thus represents a combined force of various existing structures whose objective is to carry out geophysical and volcanological research, also for civil protection purposes through its collaboration with the DPC. A highly important and innovative aspect in the volcanological field, is that the INGV is by law a component of the national service of civil protection. Moreover, study and monitoring activities, concerning the assessment of hazard and danger, are carried out jointly by agreement with the Department of Civil Protection.

After the beginning of the joint operation in 2000-01, the first emergency in which the DPC-INGV coupling actually worked in complete integration was during the eruption of Etna in 2002-03. This very complex eruption engaged the two agencies in synergy on various aspects. In a framework of active collaboration, the INGV used the continuous multi-disciplinary monitoring to update and interpret the evolution of the phenomena underway (fracture propagation, evaluate seismicity, update lava field development, simulations to forecast the routes of lava flows, geophysical and volcanological parameters to monitor the activity, surveys of seismic damage). The INGV and DPC then jointly tackled various problems and critical events associated with the eruption. Many actions were focused on mitigating the risk and directed towards decision making for civil protection purposes and for the safety of the population. In particular, the continuous thermal monitoring of the lava flows from aircraft made available by the DPC allowed following the evolution of the lava flows with constancy, and the simulations enabled predicting the routes of the flows. These aspects enabled the DPC to quickly and aptly intervene in positioning the diversion barriers of the flow on 20-22 November, 2002 in order to protect the tourist centre on the high southern slope.

The full collaboration of the INGV then continued in other very important aspects, such as seismic zoning in order to evaluate areas at greatest risk with the aim of allowing the DPC to best plan the legislative procedures on behalf of damaged towns, and the appraisal of the studies that followed and actions to be undertaken in order to improve monitoring volcanic clouds. In particular, during the 2002-03 eruption, this latter aspect proved to be a prime critical hazard, in so far as it caused major problems to infrastructures in Catania including the repeated, sometimes extended, closure of the international airport.

While the eruption at Etna was fully underway, there was also the sudden emergency of the eruption at Stromboli, compelling the scientific community and the DPC to face a maximum limit scenario that had never taken place in previous decades, namely two contemporary eruptions, both particularly complex, occurring at two different volcanic edifices.

The eruption of Stromboli, as explored in several other chapters of this Monograph, raised important new issues (flank instability and tsunami, summit crater area surveillance, necessity to rapidly upgrade the entire monitoring network) that further strengthened the collaboration and understanding between the DPC and INGV.

In this work, the crucial moments of the beginning of the eruption with the first important stages of appraising the phenomenon are outlined; then the main actions rapidly undertaken in order to upgrade the monitoring and volcanic surveillance are described; lastly, the scientific activities planned and conducted in the successive months are illustrated that, through the profitable collaboration between DPC and INGV, have led Stromboli to become one of the best monitored volcanoes in Italy and indeed the world.

2. Onset of the eruptive activity and the associated emergency

Ordinary activity of Stromboli is characterized by persistent explosive activity of strombolian type with an average of 3-5 events/hour. The explosive activity is characterized by unexpected major events that generally occur a couple of times a year. Much more energetic and violent explosive phenomena, defined as paroxysms, occur every 5-15 years on average (Barberi et al, 1993). The historical lava flows come from craters and effusive vents in the Sciara del Fuoco (SdF) depression and therefore the lava flows remain confined to this area (Fig. 1).

In 2002, the permanent monitoring at Stromboli managed by the INGV comprised a number of seismic stations of the regional network of the Aeolian islands, 4 permanent GPS stations, two bore-hole tiltmeters and a video camera installed on the top of the volcano about 100 m above the crater area (Fig. 1). Geochemical monitoring of the fluids emitted from the soil and craters was carried out periodically.

In the first part of 2002, Stromboli showed alternating stages of greater and minor ordinary explosive activity that was interrupted by two major events on January 23 and July 24. In the next months, the ordinary explosive activity underwent large fluctuations, both in hourly frequency as well as intensity (height reached by clasts) with an increase in October (8-10 events/h) and a peak in the second week of November, when a continuous emission of spatter was recorded from the northern crater with numerous explosions that exceeded 150 m in height (internal reports, at http://www.ct.ingv.it).

Following this increase in explosive activity in November, thermal surveys were carried out from the helicopter provided by the DPC, that revealed a significant increment in the temperature inside the craters and confirmed the very high level of magma close to the crater rim with small overflow from crater 2 (central vent) that had produced flows limited to a few tens of meters inside the depression of the Sciara del Fuoco (SdF).

The seismic stations, which recorded tremor with the normal fluctuations in amplitude during 2002, showed maximum values on 14-17 November at the same time as strong explosive activity. Permanent tilt networks and GPS did not detect any particularly anomalous trends (internal reports, at http://www.ct.ingv.it).

Therefore in November the assumed picture was that of a possible effusive eruption with spillage of lava from the northern crater, which owing to the summit morphology might produce a lava flow inside the of SdF depression (Fig. 1). This scenario, which would not have led to any great risk, was the phenomenon that indeed happened on 28 and 29 December when a lava flow occurred in the SdF, a week after highly anomalous CO_2 flux values were recorded at the crater rim (Carapezza et al., 2004) and 4 days after an abrupt increase in the explosive activity comparable to the peak values of mid-November (internal reports, at http://www.ct.ingv.it, Calvari et al., 2005).

In the first days of the eruption, though the complex eruption of Etna was fully underway, the INGV organized various activities for further evaluation of the phenomenon in progress at Stromboli. In particular, with the support of the helicopter of the DPC many over-flights for the visual and thermal surveillance of the activity were undertaken everyday, with consequent mapping and updating of the extend of the lava field. From the first day, the INGV set up a website dedicated to the eruption, releasing official notices, the first reports, images, maps and description of the monitoring networks.

More or less without warning, in an unexpected and unforeseeable way given the data in hand, on December 30,the effusive phenomenon was outstripped by the landslide of the SdF into the sea. This landslide, triggered by the movement begun in the submerged lower part of the SdF (Tommasi et al., 2005), caused a tsunami that mainly affected the northern part of the island. There was damage to various structures (Tinti et al., 2005) but fortunately no loss of life thanks also to the fact that the island has few tourists in the winter.

In the days/hours preceding the landslide, no particular seismic activity or any increase in amplitude of the tremor was detected. No significant variations in the permanent devices of ground deformation (GPS and tilt) were recorded either, although indeed all are located outside the SdF (Bonaccorso et al, 2003).

What then proved to be the true prelude to the phenomenon, though not provoking anomalies in the existing geophysical networks, was observable only in the images obtained from the helicopter approximately an hour before.. These showed a first trace of the edges of the landslide scars (Fig. 2a). In the early afternoon of December 30, just after landslide occurred, another over-flight was made (Fig. 2b), and then another one on 31, when the dust and landslides had ended and the collapse sectors were very clear (Fig. 2c) (Bonaccorso et al, 2003; Calvari et al, 2005).

Between 30 and 31 December, the INGV produced a broad multi-disciplinary report for the DPC (INGV-CT, 2002) that gave a picture of the events underway with specific reference to the landslide phenomenon of the SdF and consigned it to the Chief of the DPC who was in Stromboli from 30 December to coordinate the first interventions of civil protection. The report contained the interpretation and description of the phenomenon, established that it involved two landslide bodies, determined the exact times of the event, provided the estimate of the volumes involved and traced the probable scenario. In the following days, the group called “Emergeo” for the survey and quantifying of the effects of the *tsunami* also entered into action.

From 30 December, the phenomenon of the flank landslide of the SdF and the *tsunami* changed the expected scenario and consequently the hazard level raised.. In the reports of the next days, the INGV indicated to the DPC the further actions to be undertaken for integrating the already existing monitoring as described in the next paragraph. In these first critical days, the website of the INGV became a fundamental instrument for the transmission of correct information. The main data acquired was shared with the DPC and, successively, selected and issued on appropriate web pages. This became a key aspect for the diffusion of scientifically correct news and support for the DPC in regulating reports with the media, an important link with the population. An instrument, among other things, to counteract speculation and unwarranted alarmism, ever present on occasion of natural events like those associated with an eruption.

In general, for a range of scientific aspects the INGV support became essential. It soon played a vital role for the DPC in the successive briefings on the state of activity of the volcano and for the further planning of monitoring actions to be undertaken. Many of these meetings then took place in presence of the Commission of Great Risks, a consultant organ of the National Service of Civil Protection for the activities aimed at appraising the various hazard hypotheses , which has always approved the lines proposed by the INGV.

From the beginning of the eruption, the DPC promptly took on, as its duty by law, the general coordination of the activities of civil protection, involving the support of air and naval craft, and staff from various military bodies (Police, Carabinieri, Fire Departments, Forestry Corps, Coastguard, and Alpine Guides of the Finance Police). In particular, the DPC regulated the activities and flow of people to the island, that were restricted to the staff of civil protection and authorized research agencies, provided helicopter support and guides for the reconnaissance of the lava flow and the stable and landslide areas. Moreover, an operational Center of civil protection that also acted as an observatory for monitoring, called *Advanced Operational Centre* (COA), was quickly set up in the San Vincenzo locality (Fig. 3) was quickly undertaken. In a few days, this observatory was to become the advanced centre of the DPC for the coordination of all the activities of civil protection. It would also host the acquisition, intentionally centralized here, of the permanent geophysical and volcanological monitoring systems on the island.

The COA became the base shared by the DPC and scientific community for the daily briefings, usually in the afternoon, that provided the latest on the volcano’s state of activity, on the recorded measurements and the activities in progress. This centre was also open to researchers from the various Italian universities that collaborate in different areas to integrate the existing monitoring (photogrammetry, bathymetric and marine measurements, infrasonic signals, SAR measurements) All this allowed the broad based circulation and sharing of information and research in course, that in the successive weeks became a unique occasion to look in depth into the eruptive activity, the interpretations of the phenomenon and actions to be taken in a continuous and permanent way.

3. Main immediate interventions

Following the eruption, numerous activities were rapidly begun for the immediate evaluation of the recent phenomena and in progress. The DPC immediately made some helicopters available to the scientific community for thermal and visual monitoring, for the repair of the out of order stations and for the ordinary maintenance of the existing observation systems. Moreover, the DPC quickly started the restructuring of the COA, upgraded the information and calculation systems, set up spaces to allot permanent rooms for the acquisition and visualization of various data and boosted the networks dedicated to data transmission. In particular, with the aim of optimizing the transmission and information connections, various activities like the installation of connections to the Internet, activation of wireless networks and dedicated fibre-optic links for the connection of different sites and monitoring stations to the COA, were carried out.

The data of the permanent seismic networks and the video camera images are transmitted to the COA and then sent on to the INGV operation rooms of Catania and Naples, that work 24 hours a day and thus contribute to the surveillance at a distance.

In order to operate effectively, the INGV was subdivided into 4 disciplinary fields: volcanology, seismology, deformation and geochemistry (Table 1), each coordinated by respective research supervisors and the directors of the INGV structures involved in the emergency (Catania, Naples and Palermo). The supervisors of these four fields, or their substitutes, then participated at the daily briefings at the COA and drew up official notices everyday and periodic reports on the activities being undertaken. A synthetic picture of the various disciplinary activities performed by the INGV is shown in Table 1.

The very first action, following the information from the already existing permanent networks (seismic, GPS, tilt, geochemistry and video camera), concerned an immediate contribution to the control of the different elements, such as the state of activity of the crater area and its stability, the monitoring of the SdF and the unstable landslide area, as well as the surveillance of internal sources. A general picture of the first interventions realized by the INGV is given in Table 2.

The use of the thermal cameras, in frequent daily flyovers, soon proved indispensable, since they enabled detection of morphologic variations in the craters even in conditions of abundant gaseous emissions (Calvari et al., 2006), that usually encircle the craters with an impenetrable cloud, and moreover allowed monitoring of the depth of the magmatic column in the conduits. Surveillance of the SdF and the related lava flow, with the thermal cameras allowed to monitor the opening of new fractures, highlighted by their permeability to high temperature magmatic gases, and the shifting of effusive vents and calculation of the effusion rate (Calvari et al., 2005, 2006; Harris et al., 2005; Lodato et al., 2007).

On December 30, we collected ash samples at 2 different localities on Stromboli. We carried out grain-size and morphological (by scanning electron microscope) analyses on these samples. Overall therefore, the characteristics previously described did not supply indications of a fragmentation of a magmatic type, caused by the increase and breakage of the vesicles, but they could be imputed to other processes such as mechanical abrasion and/or interaction of the magma with water. However, monitoring the gaseous emissions of the summit conduits became fundamental, and FTIR measurements were undertaken to determine the SO_2/HCl relationship that, in order to combine safety and speed, were made from the helicopter supplied by the DPC. The measurements showed a minimal variation between September 2002 and January 2003, indicating that the eruptive activity was not due to a strong increase in the input rate of magma in the system. The study of the main chemical parameters was intensified by mnitoring the degassing on the ground near the inhabited areas as well as in the summit crater zone (Carapezza et al., 2004, Brusca et al., 2004), and through Cospec remote measurements (also with the aid of boats made available by the DPC) of SO_2 emission from the plume (Ripepe et al., 2005).

Following the landslide events, evaluation of the fracture field inside the SdF and the stability of the crater area still remained to be done. To this end, a structural survey was carried out that highlighted fractures that could be differentiated and described separately by their genesis, kinematics and evolution. In particular, it was confirmed that the crater area was collapsing but not subject to gravitational sliding (Acocella et al., 2006). This aspect proved very important as it allowed excluding a broader sliding with the possible involvement of the craters, that could have led to explosive activity triggered by rapid decompression. For the evaluation of the movements of the crater area and the SdF, with the aid of the alpine guides provided by the DPC, geodetic reflectors were installed in the crater area (measured from the upper rim of the crater area) and in the upper part of the SdF (measured from the low southern rim of the SdF). The measurements were repeated daily, in the summit area with the support of the helicopter and the guides, and allowed obtaining a first picture of the movements that confirmed the summit stability and defined the slip rates of the SdF (Puglisi et al., 2005).

The first phase was completed with the installation of broad-band seismic stations, to be boosted in the successive weeks to configure a new network for the real time monitoring of fundamental parameters associated with explosive activity (VLP events, localization and mechanism of the seismic source) (Auger et al., 2006).

4. Main scientific actions planned and undertaken in the course of 2003

In the successive weeks after the beginning of the eruption, together with the immediate tasks, the INGV planned various scientific projects to further implement the monitoring of the volcanic activity and the unstable flank of the SdF. The proposals were discussed during the daily briefings at the COA, and also officially presented in the meetings that the DPC held in the presence of the Commission Great Risks. The projects were approved by the DPC and then backed both by logistic support as well as funding regulated by an appropriate agreement between the DPC and INGV.

The program of the planned and undertaken activities was particularly wide in scope and tasking, and included multiple activities (Table 3) made possible by the logistic and operating support (communications, boats, helicopters, guides) made available by the DPC.

A high density broadband permanent seismic network, composed of 15 stations, was installed with the precise objective of : locating in real time the superficial and deep volumes involved in the mechanism of accumulation and release of explosive energy; identifying in real time the mechanisms of release and volumetric variations of sources of the single explosive phenomena; localising and defining the geometry of the conduits of the rising fluids, by monitoring variations with time.

Geochemical monitoring was upgraded, both in number of sites and frequency of sampling, for the evaluation of the gas emissions. In particular, the program and activities included the discontinuous monitoring of the thermal aquifers and the diffuse degassing from the ground (areas of the inhabited centre) and fumarole gases, as well as profiles of spontaneous potential and radon in the summit area (Brusca et al., 2004).

Moreover, permanent stations for the continuous monitoring of the chemical-physical parameters of the aquifers and of the emission of the CO_2 from the ground (inhabited centres and crater zone) were installed (Inguaggiato et al., 2004; Capasso et al., 2005). Special attention was given to the flows emitted from the central conduits by the installation of a network composed of 4 permanent stations equipped with "*mini doas*" geochemical sensors for the continuous detection and monitoring of the SO_2 flow from the craters.

Particular attention was given to the problem of the evaluation of the activity and movements of the summit area and the SdF. The visible video camera on the upper rim of the crater was integrated with another permanent infrared video camera, and two more permanent video cameras were installed (thermal and visible) on the northern rim of the SdF to monitor the effusive activity in the SdF.

A new aspect, very difficult to achieve, was monitoring the movements of the SdF that owing to its harsh morphology did not allow easy access and made the installation of permanent stations difficult. It was decided to proceed with a dual control provided both with GPS stations, installed inside the SdF by the aid of the helicopter, as well as an automatic geodimetric station situated at a distance. In particular, a real time GPS array for the continuous monitoring of movements, acquisition rate 1data/s, has been installed in the summit crater area and high SdF (Puglisi et al., 2005). Therefore, the GPS summit network continuously monitored a few points installed in key positions. For a greater density of check points inside the landslide area of the SdF, which proved difficult and dangerous to access, it was decided to install simple reflecting geodetic prisms with the aid of specialist guides. These were measured daily in the first weeks by EDM measurements and then in the successive months it was envisaged to permanently install an integrated theodolite (automatic measurement of angles and distances, remote controlled) positioned on the low northern rim of the SdF. In addition to monitoring the slip of the landslide area, the deformation measurements have had a fundamental role in real-time evaluation of the processes of migration of the effusive vents in mid- February, as well as understanding the mechanisms and effects associated with the paroxystic explosion of 5 April 2003 (Mattia et al., 2004; Calvari et al., 2006).

Finally, for complete geophysical monitoring, the INGV carried out the installation of a continuous gravimeter to control mass movements and an array of three permanent magnetic stations.

The final picture with the map of the permanent devices installed in 2003, following the planned activities is shown in Figure 4.

In order to complete the monitoring picture with the integration of specific disciplines that are not fully of INGV competence, the DPC also started and financed collaboration with university institutes. Various activities in full synergy with the activities planned by the DPC-INGV included the bathymetric surveys around the island (Tommasi et al., 2005), the interpretation of repeated aerial photogrammetry (Baldi et al., 2005, 2007), the installation of a SAR device (*synthetic aperture radar*) on the ground located on the northern rim of the SdF to measure the movements of the upper part of landslide (Casagli et al., 2003, 2007), and the upgrading of a permanent network of infrasonic sensors (Ripepe, 2007).

The two dramatic phenomena during the eruption course were the SdF flank failure with the associated tsunami and the paroxysm explosion during the effusive activity. The learned conclusion was that the first was an unexpected event, though in the future it could be better surveyed, while the second was an unpredictable event and more effort is needed to try to detect possible valid precursors.

As above described, the permanent integrated theodolite, automated and remote controlled and the ground based SAR device, were installed for the control of the movements of the SdF. Moreover, an automatic procedure of detection and reckoning of the seismic events provoked by small landslides was implemented.

These instrumentations and techniques should allow to monitor the stability of the flank and its possible accelerations.

A more difficult issue, and also an open challenge, is the detecting of possible valid precursors associated with the paroxistic explosions. Significant chemical changes from the main craters emission were observed a few days before the paroxysm (Aiuppa and Federico, 2004; Carapezza et al., 2004). These changes were detected only because the sampling frequency was increased from week/months to daily, this indicating the need to use automatic continuous stations in future monitoring.

The continuous GPS and seismic station showed near co-explosive signals, which are important to study the source mechanisms, but did not show a valid precursor signal. An important planned intervention is the installation of instrumentation with high sensitivity and precision such as deep strainmeters, installed at 150-200 m depth, and borehole tilt, installed in the summit crater area in order to verify the possibility of detecting precursor signals.

5. Concluding remarks

The eruption of Stromboli prompted an enormous effort in various monitoring activities. For the first time in Italy, and in such a brief time, there was an immense and complete development and upgrading of the observation systems on a volcano during an eruption. This effort was characterized by the capacity of the joint DPC-INGV both to respond in a short time with immediate interventions as well as plan further multiple scientific activities over the medium term.

This commitment to optimize the monitoring was in complete armony with numerous research joint projects started in the DPC-INGV agreement on Stromboli and then continued in a further agreement in the three years from 2004-06 when, in addition to the maintenance of the monitoring systems, part of the research plans with objectives for civil protection purposes was started. In this part of the agreement dedicated to the research projects, a particular session was foreseen for Stromboli and numerous studies involving many other institutes of research and university departments have been carried out.

Therefore the eruption of Stromboli has also instigated a commendable process of feedback between monitoring and research, which re-enforces these two elements and lays the groundwork for a modern and effective enactment of the service of civil protection.

In particular, the vision of the system of civil protection envisaged by Italian law, in which the DPC promotes and coordinates of the administrations of the State during emergencies and the INGV supplies scientific support, has proved valid and functional. The eruption of Stromboli has therefore completed, and at the same time validated this model of collaboration and has highlighted the aspects of mutual synergy, demonstrating that the Italian system of civil protection has an unity and effectiveness in the management of volcanic hazard.

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Captions

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Figures 1 - Island of Stromboli. Map of the permanent monitoring devices in 2002.

Figures 2 - Sciara del Fuoco (SdF) taken from the North: a) 30 December 2002, 12:00, one hour before the landslide, with the opened fractures highlighted in red the traces of the successive landslide scars in yellow; b) early afternoon 30 December 2002, right after the landslide in the SdF; c) 31 December, after the landslide with scars and dimensions of collapsed bodies highlighted in yellow.

Figures 3 - Island of Stromboli from above with view of the location of Advanced Operational Centre (COA), that was to become the centre shared by DPC and scientific community to coordinate and monitor the activities undertaken for monitoring and surveillance.

Figures 4 - Island of Stromboli. Map of the permanent devices set up following the actions in 2003. The comparison with the former situation until 2002 (Fig. 1) shows the vast and complete development of the observation systems installed and working in a very short time.

Tables

Table 1 - Outline of the disciplinary fields of the INGV for the monitoring and surveillance of Stromboli.

Table 2 - Main immediate scientific activities of the INGV supporting already operating systems

Table 3 - Main scientific interventions planned and realized in 2003

Table 1 - Outline of the disciplinary fields of the INGV for the monitoring and surveillance of Stromboli.

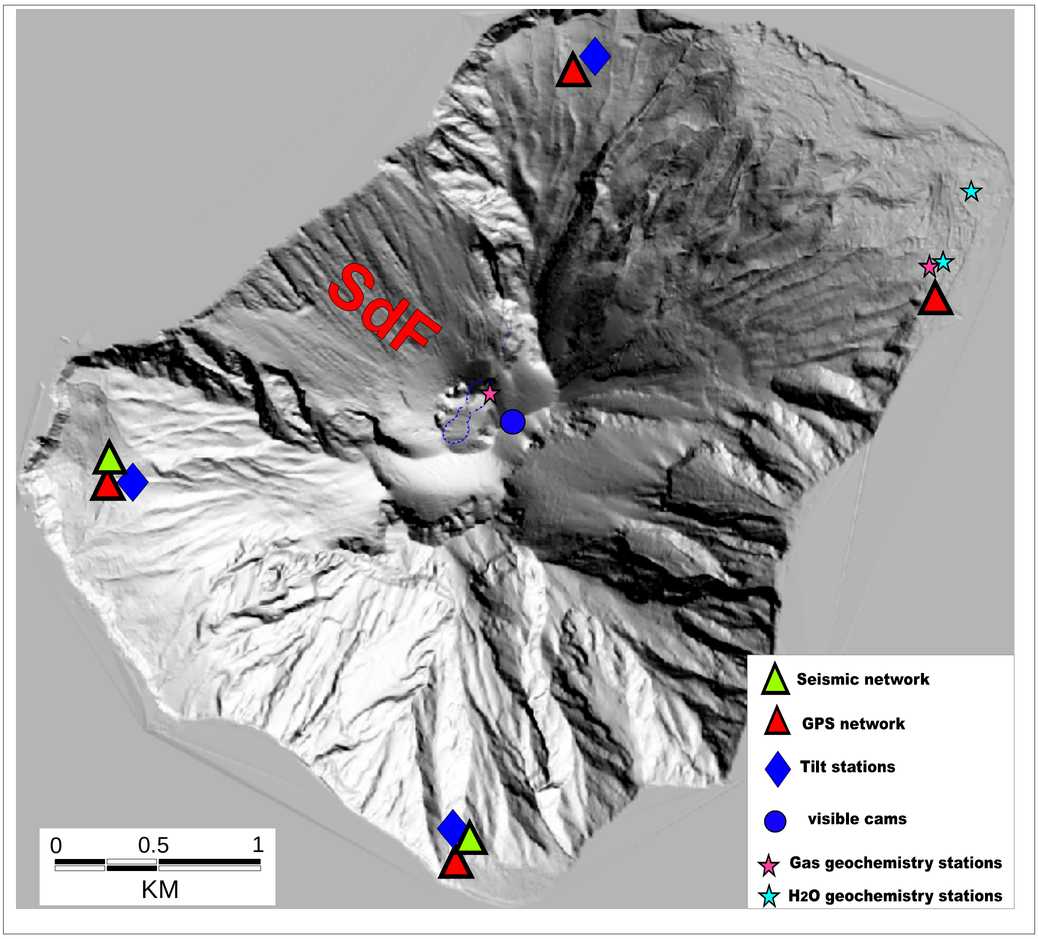
SEISMOLOGY	VOLCANOLOGY	DEFORMATION	GEOCHEMISTRY
- permanent seismic network - upgrading and installation of broad band sations - real-time analysis of the mechanisms and parameters of the seismicity - H24 surveillance in the Operations lRoomll	- Geological and structural investigations - mobile thermal camera helicopter survey - volcano products sampling - products laboratory analysis (petrology, mineralogy, XRF) - permanent camera network	- permanent GPS network - high-frequency summit permanent GPS network - permanent tilt stations - EDM measurements (summit and unstable areas) - automatic geodetic station	- Gas sampling from : soil, water and fumaroles - gas and temperature permanent stations - SO2/HCl plume Ftir measurements - SO2 plume UV scanner permanent network

Table 2 - Main immediate scientific activities of the INGV in support of the already operating systems \

Type	Activity	DPC support
Thermal survey	Monitoring and thermal mapping of the summit crater areas, the flow and the SdF with aerial coverage	helicopter
Seismology	Installation of first permanent broad-band stations to update the existing network	helicopter
Deformation	EDM measurements for the control of the stability of the summit area and movements of the SdF	helicopter and guides
Investigations on tsunami effects on the coast	Survey, monitoring and appraisal of the effects of the tsunami on the coast	boat and guides
Structural “analysis”	Analysis of the structural field and fractures associated with the eruption, and evaluation of the stability of the crater area	helicopter and guides
Petrological analysis	Analysis of emitted ash for the characterization of the explosive process	guides
Fluid Geochemistry	Intensification of the sampling of ground degassing around inhabited areass and in summit crater	helicopter and guides
Remote sensing Geochemistry	FTIR measurements for the control of the HCl/SO2 ratio from the plume	helicopter
Remote sensing Geochemistry	Measurements with Cospec technique to control SO2 release from the plume	boat

Table 3 - Main scientific interventions planned and realized in 2003

Type	Activity
Seismic network	Broadband network installation
Webcam network	Set up of network of two sites, each with 2 webcams (visible + thermal) to monitor summit and the SdF
Geochemistry of fluids (periodical measurements and permanent instruments)	Upgrading of the discontinuous monitoring of the thermal aquifer the degassing from ground and fumarole gases, measurements of potential and radon in summit area
Geochemical remote sensing (permanent Array)	Installation network of 4 permanent stations for the continuous tele-suveying and monitoring of the SO2 flow
GPS real-Time network	Installation of permanent GPS real time array (1 data/s)
Automatic Theodolite	Installation
Gravimetric and magnetic permanent network	Installation of a permanent gravimeter and an array of permanent magnetic stations



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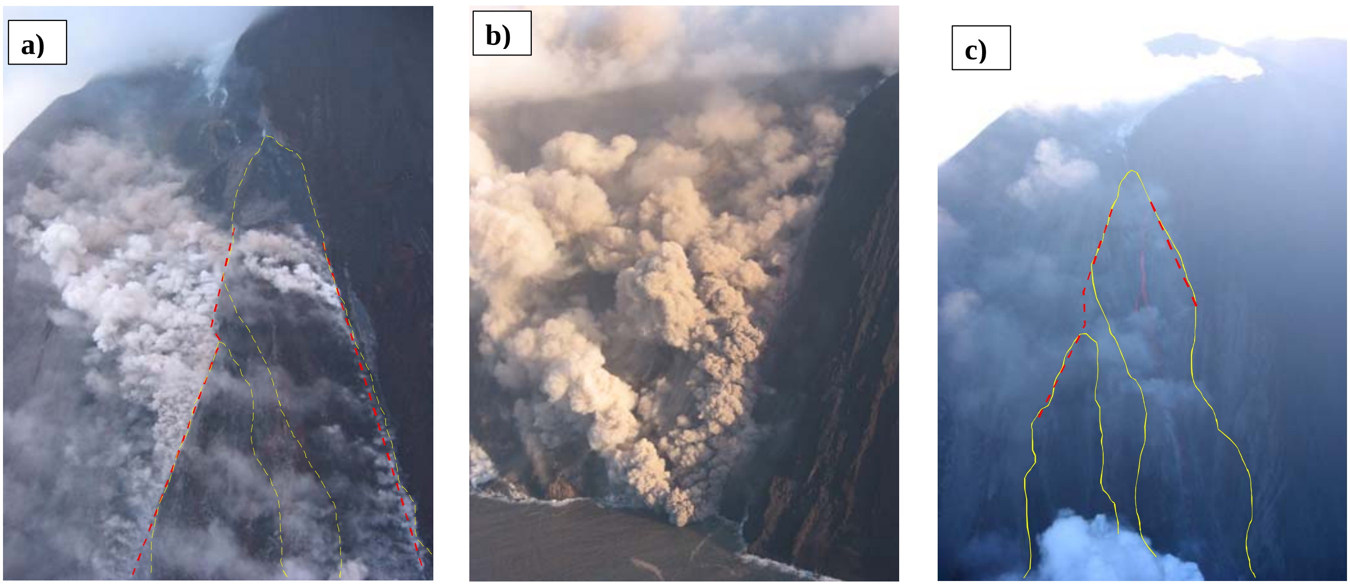

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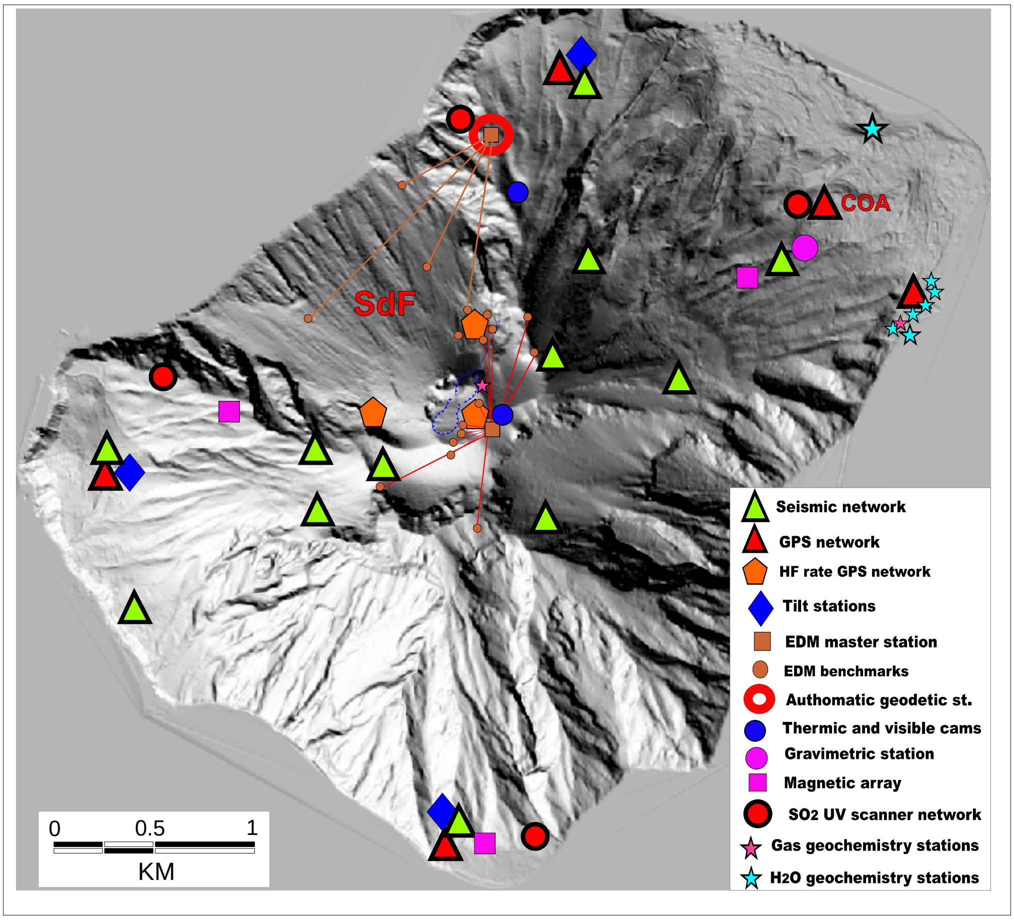

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