Volcanic Risk Management: the Case of Mt. Etna 2006 Eruption

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Abstract
Mt. Etna volcano is located in a very populated area of eastern Sicily (Italy). Its permanent degassing activity from summit craters and frequent eruptions impact significantly on town habitations and cultivated areas. In the latest years Etna has produced copious ash emission causing great losses to local economy and causing serious hazards to national and international air traffic over Mediterranean area and the often closure of Catania airport.
In July 2006 eruptive vents opened on the East and South flanks of the summit craters showing irregular explosive and effusive activity lasting 6 months.
This eruption represented the opportunity to perform the pre-operative test of FP6 Eurorisk-Preview (Prevention, Information and Early Warning) project aimed to develop tools for monitoring volcanoes.
The test was performed during two temporal phases: the first one of early-warning was aimed to measure ground deformation and the second one during the crisis to survey volcanic ash produced during the explosions.
The ground deformations were measured through the elaboration of SAR data. Beside the geophysical objectives, the test was also important to check data availability and efficiency of European Space Agency procedures. The pre-operative test has been peculiar to understand and quantify the delivering time of the final satellite products expected from the Volcanological Observatory in operative case. The analysis of July 2005 - July 2006 SAR data showed a pre-eruptive inflation trend in agreement with the ground network of GPS data. The magmatic source, that produced the September - October activity, has been located about 2.7 km below the summit craters.
During the crisis phase characterized by paroxysmal activity, the Italian Civil Protection (DPC) in charge of airport closure in case of volcanic hazard, requested the satellite volcanic ash product retrieved from the NASA-MODIS data. An agreement between the industry Telespazio as direct broadcast of satellite data at Matera station and INGV was signed in order to elaborate the data in near-real time. The volcanic ash product provided information about: the presence of volcanic ash in the air; the affected area; the volcanic plume dispersal direction, dimensions and altitude and the volcanic ash loading.
The satellite products and the observations report have been successively inserted in a web-interface. At the same time the observations report has been linked to the DPC dedicated Web-GIS interface that allows in a short time the availability of volcanic ash information to DPC in support to their decisions.

Keywords: Earth observation data, Volcanic hazard, Web-GIS

1.1 Introduction

Active volcanoes are spread all over the world and are located in specific areas correlated to geologic structures. In the last 10,000 years more than 1300 volcanoes have erupted, but only half of the eruptions have been reported in historical texts. It has been estimated that every year 50 volcanic eruptions may occur threatening about 10% of the worldwide population (Andres and Kasgnoc, 1998). Considering the constant increase in human population and that many major cities are placed in the proximity of active volcanoes, the number of people subjected to the risks caused by volcanic eruptions is also increasing. Explosive eruptions represent a serious hazard not only for the human population, but also for aviation safety. Because of the increases in air routes and in the number of flights the probability that volcanic ash dispersed into the atmosphere is at flight levels is actually about 20 days/yr. From 1973 to 2000 IATA estimates that more than 1000 airplanes around the world have been damaged by volcanic ash with an economic loss of about $250 million.

In the framework of the FP6 program, the European Union has funded the Eurorisk-Preview (Prevention, Information and Early Warning) project (http://www.preview-risk.com/). The project addresses European Civil Protections with the aim of developing, at a European scale, new tools and information services to support risk management. In this framework, *Earthquakes* and *Volcanoes* platforms have been developed by a network of partners* for the operative needs of the Italian Civil Protection and using the most advanced research and technology outcomes.

Mt. Etna in Sicily (Italy) and Pico de Teide in Canary Islands (Spain) have been the volcanic test sites. Mt. Etna is the most active volcano in Europe causing several problems to the neighbouring population with its frequent eruptions. Tenerife in Canary Islands is potentially in danger since caldera collapse has occurred in past eruptions of Pico de Teide. Given the high density population and the tourism on the islands, new technologies are needed to investigate its reactivation as a seismic swarm occurred on 2004.

After intense exchange between partners, the service product chain of *Volcanoes* platform has been built according to the following steps (Figure 1):

1) Ingestion: acquisition of Earth Observation (EO) satellite historical series;
2) Core process: analysis of satellite data to retrieve scientific products and integration with ground network data;
3) Repository: build the database;
4) Distribution: build the Web portal in a Geographical Information System where the scientific products are shown and available for querying, according to Civil Protection needs.

When the service was ready for a past eruption of the Mt. Etna, a new eruption occurred in 2006. We took the opportunity to test the service during this eruption.

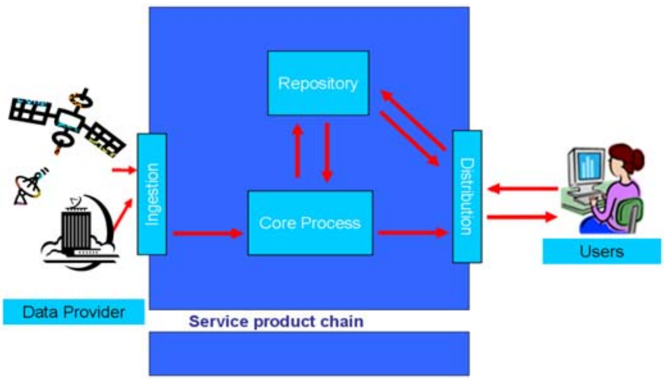

Figure1: This image shows the scheme of the service production chain.

* Project partners: ACS, COERI, DPC, EMSC, Geopapp, INGV, IREA-CNR, NOA, Telespazio, UCM

1.2. The EO products

The scientific products consist of geophysical parameters related to the volcano status, derived from the analysis of the Earth Observation data. These parameters differ according to the type of volcanic phenomena. When a volcano is in a quiescent phase the most relevant parameters are: surface deformation, surface temperature, and gas and particulate emissions into the atmosphere. A change in the volcanic behaviour is reflected in changes of these parameters. When the volcano is in the eruption phase, the relevant parameters are the velocity of the active lava flow and the volcanic ash emitted into the atmosphere. All these parameters are EO products when presented as geospatial information in the form of thematic maps.

1.3. The Web-GIS

The *Volcanoes* platform has been designed to improve access to satellite derived information. The design of its architecture has been developed to organise and harmonise heterogeneous value-added data and provide a common access point, which should be simple, efficient and comprehensive, including all data exploited by Civil Protection, and able to anticipate possible integration with data coming from other services.
To reach this goal a GIS (Geographical Information System) published on the Web (Web-GIS) was designed. The objective of the web application is to display the EO products, thanks to their spatial relationships. Data and EO products are collected and stored in a central repository based on a relational database PostgreSQL.
The Web-GIS displays EO products as images, graphs and data related to monitoring volcanic and seismic risk. It can be accessed by any web browser so that it can be exploited by authorised personnel remotely from their office, or in the field.
The system is organised in the 3 phases of the risk management:

- Knowledge and prevention
- Crisis
- Post-crisis

Image data or thematic maps are selected for display by identifying the EO product and the time window in which the data is to be searched. The Web-GIS can be reached at http://preview.acsys.it/preview/login.php. Example of EO products selected are the volcanic plume aerosol optical characteristics (Spinetti et al., 2007) in the Knowledge and Prevention section. Due to the adoption of Open Geospatial Consortium (OGC) standards, the user can integrate the data with others stored in their own environment.

2. Mt. Etna 2006 eruption

Mt. Etna (3300 m a.s.l.) is located in the eastern part of Sicily and is one the major degassing volcanoes in the world (Romano, 1982). Its quiescent state is periodically interrupted by eruptive periods characterized by lava flows and volcanic ash emissions that cause different hazards and problems to the local population. The ash fallout damages the inhabited and cultivated areas; the volcanic ash that remains in air creates serious hazards to air traffic as it spreads over the East Mediterranean area at high altitude; this causes local economic loss due to the closure of airports.
In mid-July 2006 Mt. Etna exhibited 15 days of lava flows down to an isolated area. A new eruption started in September characterized by lava flows and a series of episodic explosive activities producing ash plumes that drifted several kilometres away from the vent. These episodes occurred frequently from September to December showing weak intensity and short duration compared to 2001 and 2002

eruptions. The 2006 Mt. Etna eruption provided the opportunity to perform the pre-operative test of the project and to sharpen the development tool.

3. Surface ground deformation measured by SAR

Volcano surface changes (ground deformations) are directly related to what is happening deep below the surface. In general a surface inflation is related to feeding of the magma into the plumbing system, while a deflation is related to the discharge of magma. Most of the deformations can be detected and measured with precise surveying techniques, such as GPS, tiltmeters, EDM and most recently satellite InSAR technique (Interferometric Synthetic Aperture Radar). This technique combines several radar images recorded by Earth orbiting satellites to show subtle movements of the ground surface over time and to map ground deformation of large areas (Puglisi et al., 2008).

In the begin of the 2006 eruption we tested the efficiency of European Space Agency procedures to rapidly obtain data in order to measure ground deformation using InSAR technique (ESA provided data via Category-1 n. 3560). Figure 2 shows the InSAR core process results for the period July 2005 - July 2006. The results locate the magmatic source at about 2.7km below the summit of the craters. The source is in agreement with the volcanic activity that occurred in the period Sept-Oct 2006 (Guglielmino et al., 2007).

We understand that the operative results derived from the InSAR technique only are useful for monitoring ground deformation if they are accompanied by a historical series of deformations and a model source constrained by ground measurements (GPS data). All these information have been implemented for the Mt. Etna case.

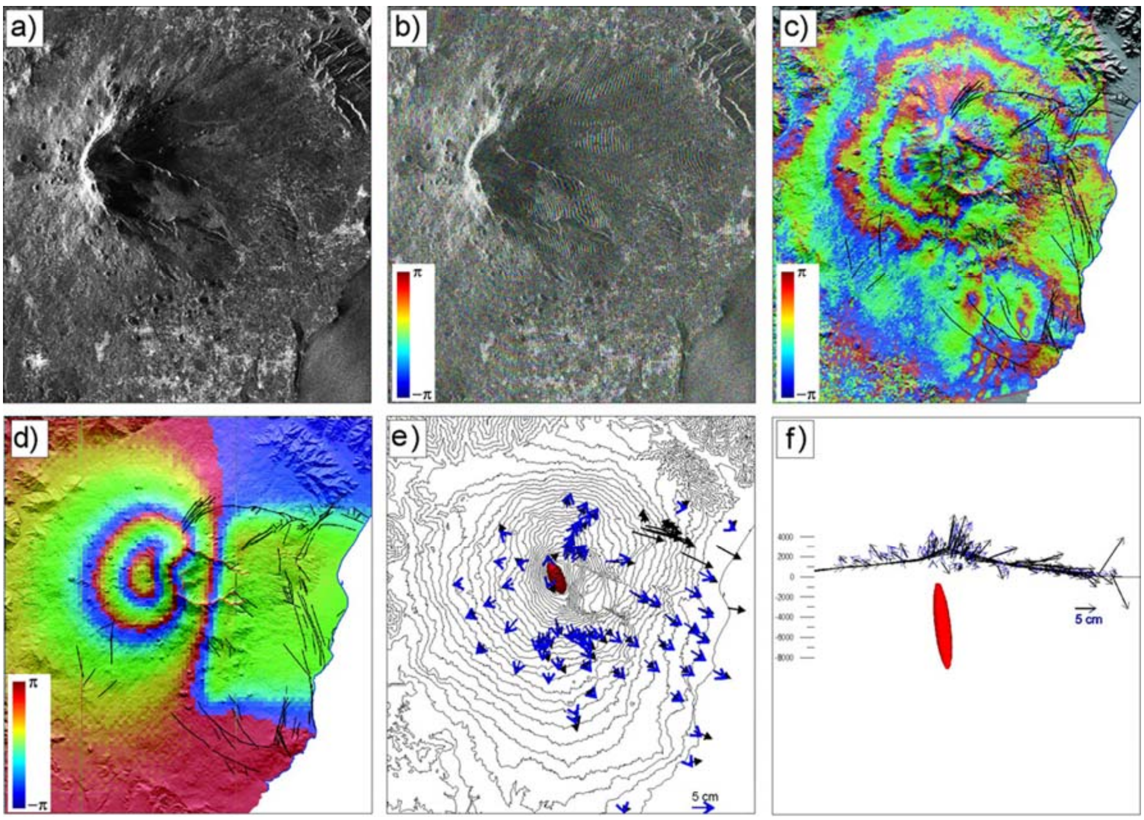

Figure 2: This image shows: *a)* ERS image. *b)* Phase interferogram obtained by combining an ERS pair from 20 July 2005 and 5 July 2006. *c)* Interferogram obtained by subtracting the terrain model. *d)* Synthetic interferogram obtained by inverting GPS data. *e)* GPS displacement vectors (July 2005 -July 2006). The black arrows represent the horizontal displacement vectors and the blue are those modelled as compatible with a volcanic pressure-source (in red). *f)* Cross section showing the source model in red.

4. Volcanic ash measured by NASA-MODIS satellites

November 24th 2006, at about 03:00 UTC, a paroxysmal event occurred with ash emission lasting about 14 hours (Andronico at al., 2009; Figure 3a). This event produced the largest volume of ash in the entire September-December eruptive period. On that day the wind was blowing from the N-NW direction. A change in wind direction caused the ash plume to move towards the city of Catania. The episode was recorded at 12:20 UTC by MODIS on board Aqua satellite (Figure 3b). The finest ash travelled more than 80 km from the summit craters. The ash fallout caused the closure of Catania Airport.

Figure 3: Mt. Etna ash plume on 24 November 2006: *a)* picture taken 30 km from summit carters (photo courtesy of B. Behncke); *b)* MODIS data on Aqua RGB image.

The pre-operative test went through the following steps:

1) The DPC requested activation of the EO volcanic ash product to project partners with an observation preformatted report.
2) Ingestion: after pre-processing, the MODIS data acquired from Telespazio through the Matera ground receiving station were automatically sent to INGV in near-real time.
3) Core process: INGV ran its scientific models and algorithms in order to derive the EO product. The Brightness Temperature Difference procedure with the atmospheric water vapour correction was applied to infrared MODIS channels to detect volcanic ash, discriminate it from meteorological clouds and identify the affected area. The retrieved mean ash optical thickness at 0.55 µm, the mean ash particle radius and the ash loading in the plume were derived to be 0.4, 3.5 µm and 3620 tons respectively.
4) Distribution: ACS developed an interactive web-interface (Figure 4a) linked to the main Web-GIS in the Crisis risk management phase. INGV created the preformatted observation report with the volcanic ash information on: area affected by volcanic ash, the volcanic plume dispersal direction; dimensions and altitude in the atmosphere and the volcanic ash loading (Figure 4b). The preformatted observation report was published in the Web-GIS via WMS standard protocol (Figure 5).

Total time processing was estimated to be less than 1 hour, after receiving MODIS data. The test end when the eruption terminate in late December.

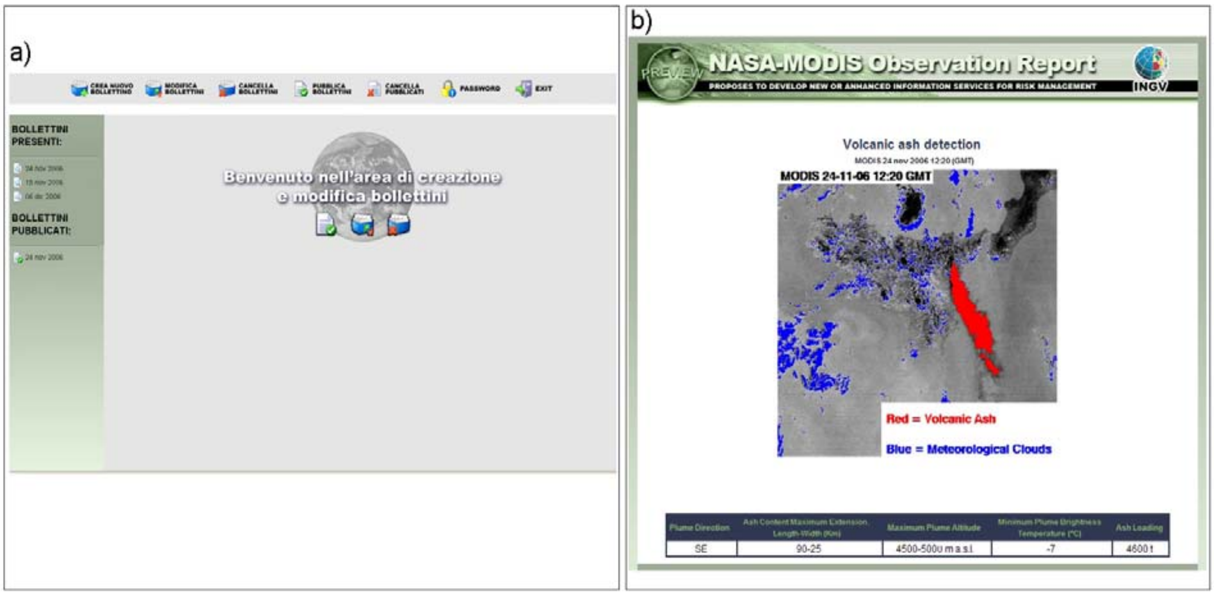

Figure 4: This image shows the report creation: *a)* Interactive web-interface where INGV insert the volcanic ash information; *b)* Web-published preformatted observation report.

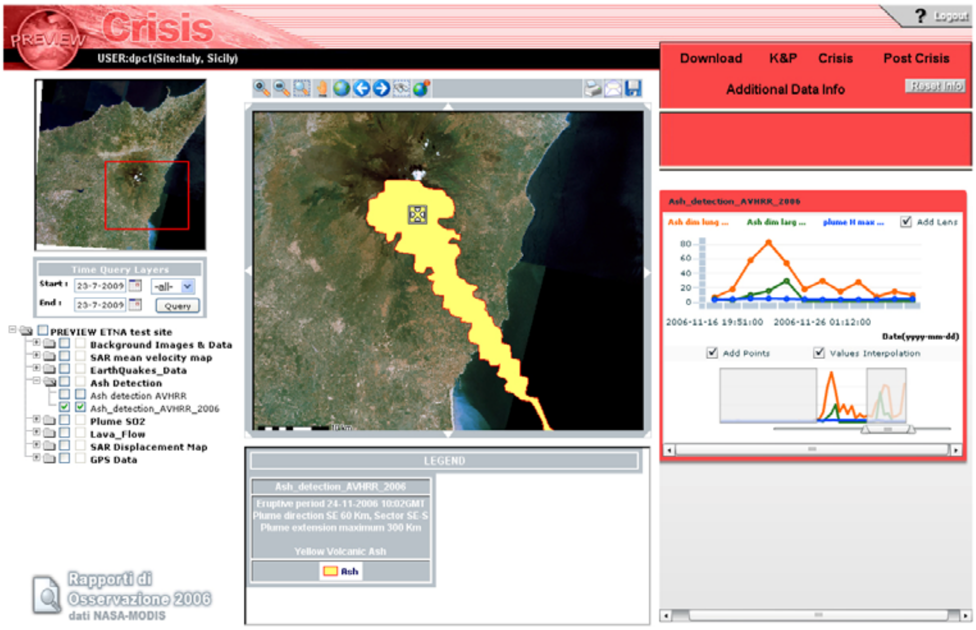

Figure 5: This image shows the Web-GIS portal in Crisis section with the selected volcanic ash EO product. In left bottom is marked the availability of the observation report.

5. Conclusions

A Web-GIS developed separately for the *Earthquakes* and *Volcanoes* platforms has been developed according to end-users requirements. The EO products relating to the selected eruption occurring at Mt. Etna (Sicily) in 2001 have been integrated with the geophysical information derived from the ground network. The Web-GIS has been designed to supply specific information in a user-friendly and efficient way and to support Civil Protection in the decision process.

During the 2006 Mt. Etna eruption we performed a successfully pre-operative test on the two phases. In the first phase, we tested the European Space Agency procedures to rapidly receive the EO data to obtain the ground surface deformation. In the second phase characterized by paroxysmal events with volcanic ash emission,

we tested the procedures to give relevant information on volcanic ash to DPC to support their decision making process. This test does not address the precise location of events for prevention and mitigation purposes, but responds to the needs of decision-makers to better understand the situation and to identify vulnerable populations.
The Preview project work and the pre-operative test is an example of successful collaboration between industry and a national body using results from the scientific community in a practical way the for the risk management.
The work carried out will be further developed to an operational stage through the new project SAFER funded by the European Union in the FP7 framework.

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