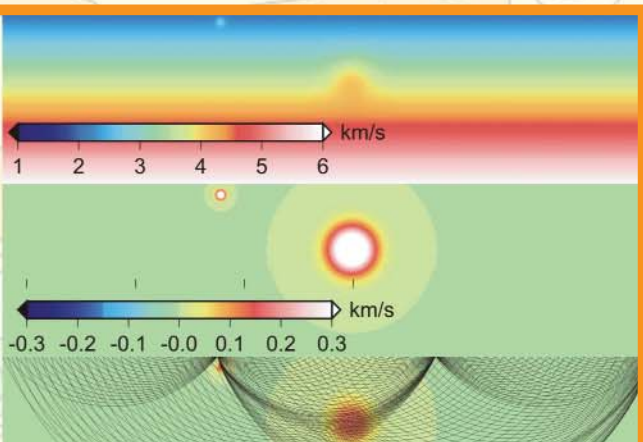
Warner Marzocchi and Aldo Zollo (Editors)

Conception, verification and application of innovative techniques to study active volcanoes

Istituto Nazionale di Geofisica e Vulcanologia

Dipartimento della Protezione Civile



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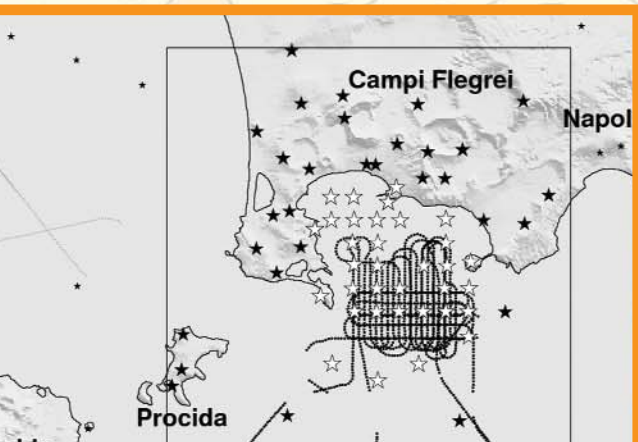

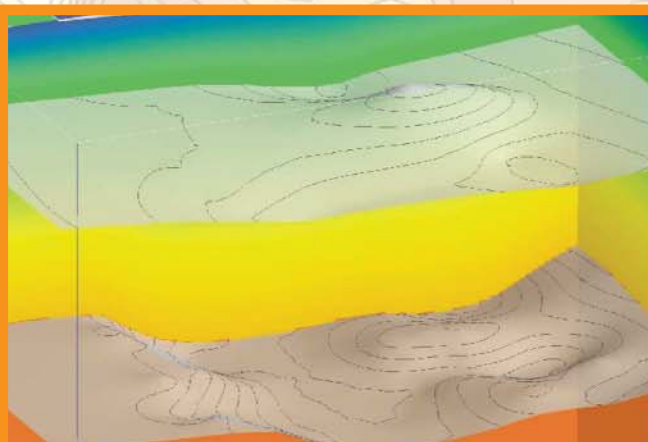

Conception, verification and application of innovative techniques to study active volcanoes

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Task 2

Use of Forward Looking InfraRed thermal cameras at active volcanoes

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Introduction

Nowadays, thermal imaging has become a common remote sensing tool for monitoring active volcanoes. The study of temperature variations within open-conduit systems, at eruptive fissures, active vents, domes, lava lakes, lava fields and other volcanic features has proven fundamental to better understand volcanic system behaviour over the short and long terms (Harris and Stevenson, 1997; Oppenheimer and Yirgu, 2002; Calvari et al., 2004; Wadge et al., 2006).
At INGV Catania Section, thermal imaging has been applied at Mt Etna, Stromboli, Vulcano and Panarea since 2001.
The instruments used are thermal cameras manufactured by FLIR (Forward Looking InfraRed) and consist in uncooled bolometers that are sensitive within 7.5 and 13 μ wavelengths. Thermal cameras are based on the capability to detect radiation emitted by bodies according to Planck's Law.
In particular, the camera we used is a FLIR thermal camera A 40 M Ethernet with a focal plane array uncooled bolometer (320 x 240 pixels), and a spectral range between 7.5 and 13 micrometers (Figure 1.). It has a standard optics 24° with spatial resolution (IFOV, instantaneous field of view) of 1.3 mrad, a horizontal view of 24° and a vertical view of 18°. This camera has also been equipped with optional filter to measure temperature values up to 1500°C with the possibility of setting up different temperature ranges.
The thermal camera can record and transfer in real time via wi-fi radiometric frames in JPG format of the observed eruptive activity according to some environmental parameters, such as external temperature, air humidity and emissivity and allows the vision of volcanic activity both day and night.
Temperature range varies between 0 e 500° C and the emissivity value $\varepsilon = 1$.
To correct the temperature of all pixels from the atmospheric attenuation

Fig. 1. Thermal camera FLIR A 40 M.

effects, we considered atmospheric parameters, such as air temperature and air humidity, in addition to the introduction of the path length (400 m) in the camera software. In fact, the radiations detected by the FLIR thermal cameras, that work in the spectral band between 7.5 e 13 μm, are affected by the absorption factor from the water spectrum, which is predominant in this band; particularly at La Fossa crater where the water content in the fumaroles is higher than the other gas species.
Because of the necessity to correct the radiometric data from the atmospheric factors in real-time, we installed a meteorological station able to interface with the camera to provide atmospheric parameters for the auto-calibration.

Thermal camera installation at La Fossa crater, Vulcano (Aeolian Archipelago)

Between 18 and 20 July 2005, L. Lodato and L. Spampinato from INGV-Catania, A.J.L. Harris from SOEST, University of Hawaii, and J. Dehn University of Fairbank, Alaska, carried out two days of thermal measurements at La Fossa crater (Vulcano Island) (Figure 2).
The survey had a dual purpose:

1. to continue thermal measurements at fumaroles performed by Harris since 1994, using infrared handheld thermometers and thermocouples (Harris and Stevenson, 1997; Harris and Maciejewski, 2000);
2. to repeat the same measurements by using FLIR thermal cameras, to test their ability for monitoring La Fossa's fumarole field.

Measurements involved four FLIR thermal cameras imaging the Lower fumarolic zone (Figure 2). Cameras were aligned in a NE-SW direction on the opposite inner flank (southern) of the crater, at distances of 50, 100, 200 and

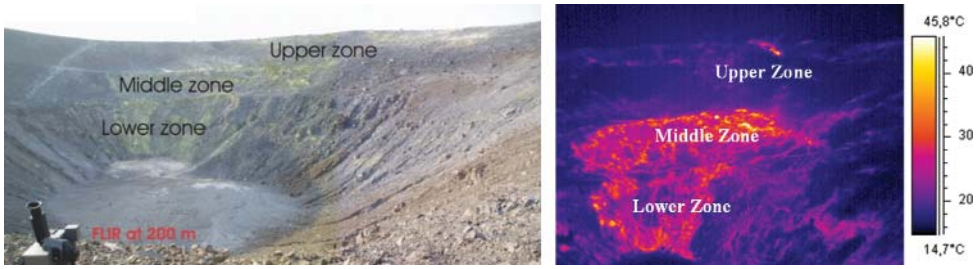

Fig. 2. Photo and thermal imaging of La Fossa's fumarole field taken from the opposite inner flank of the crater. Three main fumarolic zones, Lower, Middle and Upper zone are distinguished according to Harris and Maciejewski (2000).

400 m from the Lower zone. Thermal cameras were tripod mounted and synchronized with GMT time. GPS points for each measurement station were recorded.

For applying thermal cameras, internal calibration for atmospheric corrections of temperature for all pixels, air temperature and relative humidity were measured in situ using handheld hygrometers. Emissivity used was 0.9751, according to Harris and Maciejewski (2000) and the acquisition frequency chosen was 10 seconds.

Additionally, a 12-degree lens was also applied to the 400 m distant FLIR. This lens increased the camera magnification by a factor of two, corresponding to half of the real pathlength (Harris et al., submitted to Bulletin of Volcanology in 2007).

During the second day of measurements, a fifth thermal camera located at ~ 350 m distance from the Lower zone was used. The instrument was a FLIR A 40 M thermal camera, the kind used at Mt Etna and Stromboli permanent stations.

The analysis of thermal images collected during the entire survey proved the reliability of thermal cameras for monitoring La Fossa fumarole field. This provided us the input to develop a methodology to improve thermal data collection and the monitoring system at Vulcano fumaroles.

Indeed, the opportunity to install a permanent thermal camera could haveenabled us the possibility to:

1. record thermal images in continuous and real-time,
2. acquire images with the same easily comparable geometry,
3. control the whole system from INGV Catania main site.

Thermal camera installation

A year later, in June 2006, an A 40 FLIR thermal camera was installed at almost the same 400 m distant site from the Lower zone, chosen during the

thermal survey of the previous year. For this distance, the effective pixel size resulted ~ 50 x 50 cm. This location allowed imaging the Lower, Middle and Upper zone, and part of the fumaroles located at the northeastern crater rim (Figure 3).

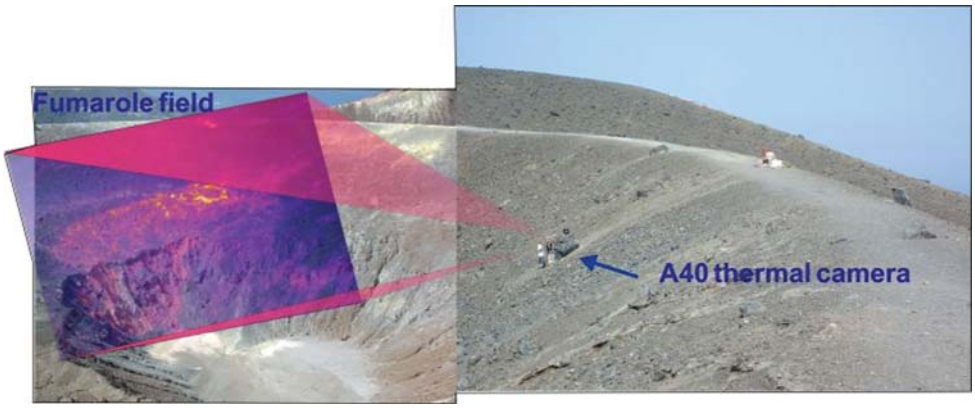

Fig. 3. Photo of La Fossa inner crater taken from the southwestern crater rim showing the A 40 location. The overlapped thermal image represents the camera field of view.

The thermal camera began acquisition at the end of September 2006 with a frequency of 30 minutes.
The installation occurred in two main phases:
– *First phase:* thermal camera installation.
– *Second phase:* weather station installation and mainboard for the interface between the thermal camera and the weather station.

First phase: thermal camera installation

In June 2006, thanks to the support of the helicopter of DPC (Dipartimento di Protezione Civile Nazionale), the thermal camera station was installed (Figure 4). This comprised an A 40 M FLIR thermal camera, photovoltaic power system and wi-fi system for radiometric data transmission.
The A 40 camera was located within a polycarbonate box supported by a steel inox structure, whereas the battery was put into a Gewiss resin box (Figure 5). To protect the thermal camera lens from alteration by volcanic gases, the polycarbonate box was equipped with an additional germanium lens. Moreover, due to high air temperatures occurring during Summer (temperatures > 60° C), the thermal station was equipped with a chronothermostat.

Fig. 4. Photo taken from La Fossa southern crater rim 24 June 2006. Helicopter of DPC Nazionale transporting the thermal station components.

Fig. 5. Polycarbonate box containing the A 40 M FLIR thermal camera.

Radiometric data transfer and thermal camera remote control are controlled by an access point equipped with a serial and Ethernet connection.
The serial connection creates the interface between the thermal camera and the weather station, while the Ethernet connection links the thermal camera with the access point.
Radiometric data are transferred by wi-fi to Lipari (INGV Catania) site, sent to Catania (CUAD, Centro Unificato Acquisizione Dati, Catania) by Garr network (2 Mbps), where they are stored on a personal computer and analyzed in real-time by IDL software. In detail, the access point, located within the Gewiss resin box, communicates with the Lipari system through a directional antenna (Figure 6).

Fig. 6. Directional antenna for wi-fi data transmission to Lipari Island.

At Lipari (Osservatorio della Marina), another access point (Alvarion) was installed for the acquisition of radiometric and atmospheric data transmitted by the thermal station in Vulcano.
The feeding system comprised two photovoltaic Kyocera panels with a steel inox structure, linked to a charge regulator through an electric cable (Figures 7a,b).

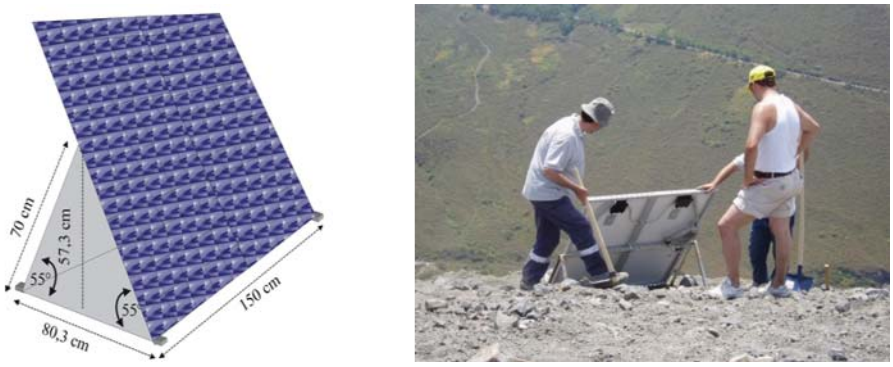

Fig. 7. Left (a), Kyocera photovoltaic panel project; right (b), photo showing the photovoltaic panel installation.

Energy necessary to supply the thermal station was calculated by considering that:
a. the thermal camera has to work 24 hours per day,
b. an average of three hours of sun light taking into account Winter and Summer,
c. without sun light, the battery has almost two days of autonomy, and
d. the whole system needs an average of 550 W/day.

Second phase: weather station installation

In January 2007, to apply corrections for the atmospheric parameters within the thermal camera internal software in real-time, a weather station close to the thermal camera was installed. The remote control, the atmospheric parameter acquisition and the interface between the A 40 and the weather station is managed by a mainboard.
The weather station is a La Lacrosse WS 2305 (Figure 8) provided of a hygrometer, anemometer, rain gauge and a temperature sensor.
The microcontroller used to create the interface between the components of the entire system (Figure 8), is a Microchip Pic (Peripheral Interface Controller) 18F258. In particular, the microcontroller reads the atmospheric parameters recorded by the weather station and sends them to the access point. Additionally, it periodically sends values of air temperature and relative humidity to the thermal camera for the autocalibration (Figure 9).
The whole system was tested in Catania before the installation.

Fig. 8. La Lacrosse WS 2305 weather station.

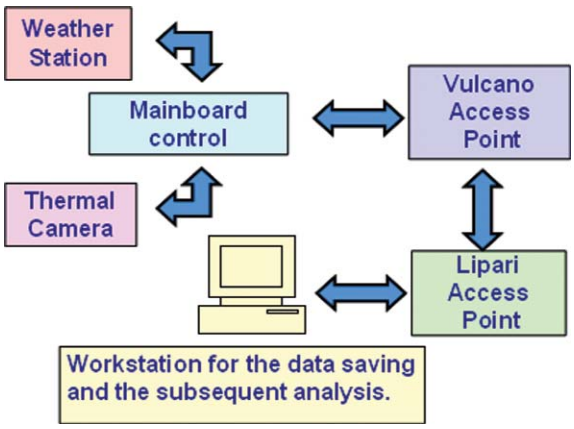

Fig. 9. Block diagram of the system.

Future development

During a survey two months after the installation of the station, we observed that it shows very clear corrosion traces due to highly corrosive gases emitted by Vulcano, even more marked than those observed at Stromboli stations (Figure 10).
For this reason, we are performing a study to carry out special protection for future installations in this kind of environment.
The polycarbonate case well preserved the thermal camera from the acid gas corrosions.

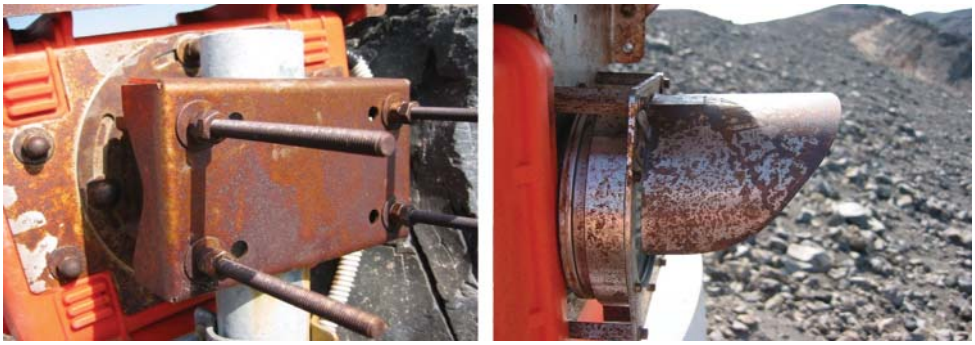

Fig. 10. Gas corrosion effects at Vulcano station.

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