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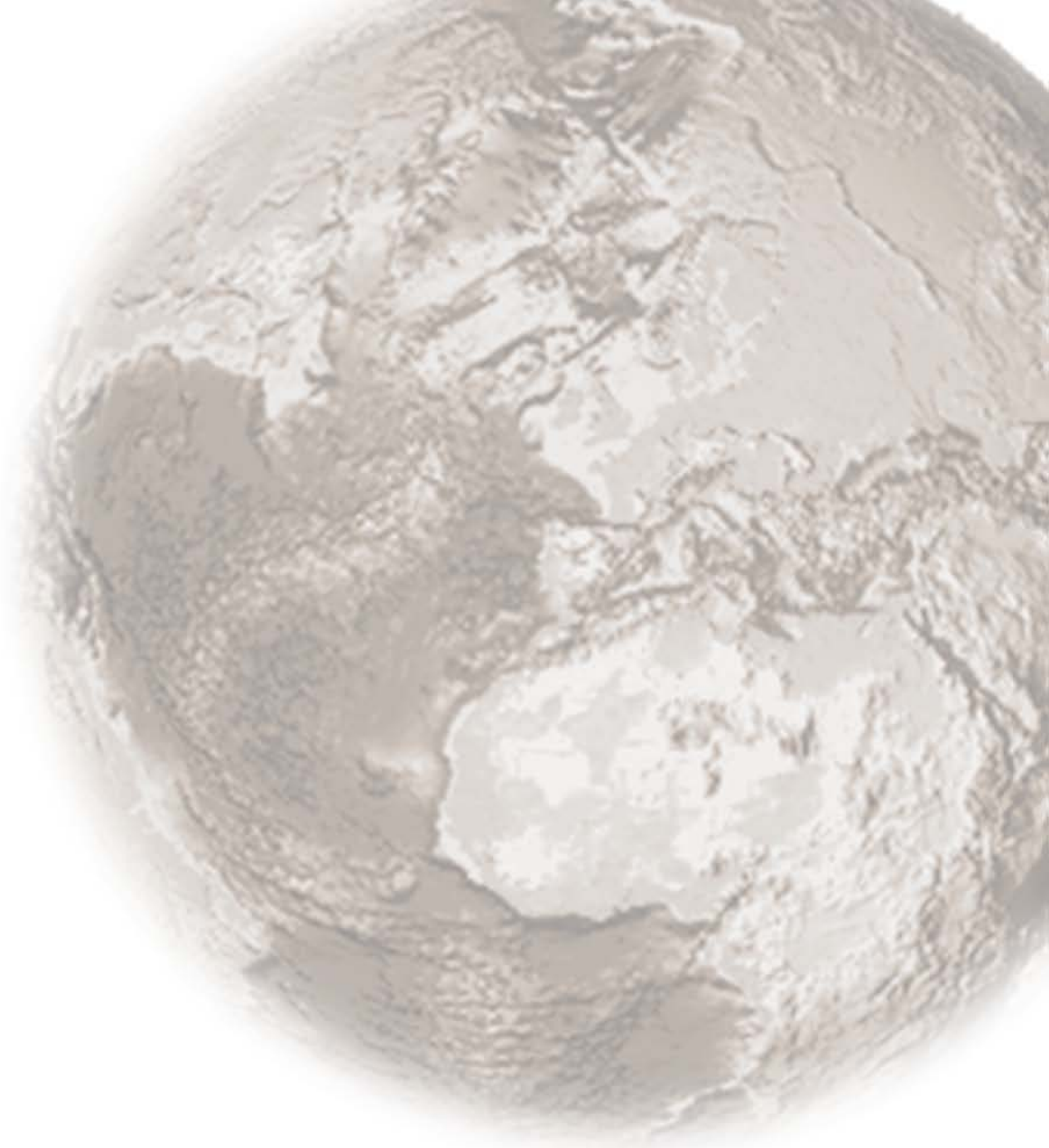

2008

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INFRARED SPECTRAL CHARACTERISATION OF SOME VOLCANIC ROCKS ON MT. ETNA WITH IN-SITU INSTRUMENTS, JUNE 2007

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Introduction

Mount Etna volcano is the tallest and most active volcano in Europe. It is characterised by four craters (Northeast Crater, Voragine, Bocca Nuova, Southeast Crater (Figure 1) and a maximum height of 3315m above sea level (asl). Etna produces frequent eruptions of basaltic magma that consist of voluminous lava flows, scoria-generating explosions and ash-generating explosions [Behncke et al., 2005]. Since the late 1970s, summit eruptions have shown an increase in their intensity, with a high rate of short-lived paroxysmal eruptive episodes [Behncke and Neri, 2003]. Such events can produce lava fountains that reach heights of several hundred meters and are accompanied by the generation of abundant tephra and scoriae that can fall tens of kilometres away from the volcano. The surface of Etna is highly dynamic, changing rapidly as lava flows are emplaced, ash falls deposit and pyroclastic cones grow. Such a system has naturally become the focus of air- and space-borne remote sensing studies, focussed on detecting thermal anomalies and measuring volcanic gas emissions. The efficacy of such studies is strongly dependent on accurate studies of the wavelength-dependent emissivity and reflectance of surface rocks. In order to obtain improved constraints on these parameters for Etna we conducted a campaign of *in-situ* ground-based spectroscopic measurements on Etna in June, 2007. A series of target sites, representative of both the present-day and oldest volcanic surfaces, were geologically and spectrally characterized. Measurements were made using an ASD FieldSpec Pro portable spectrometer operating in the 300-2500nm wavelength range for reflectance while an FTIR Bruker OPAG-22 was used for emissivity measurements in the mid-infrared. Here we present the preliminary results of the campaign and compare with satellite data.

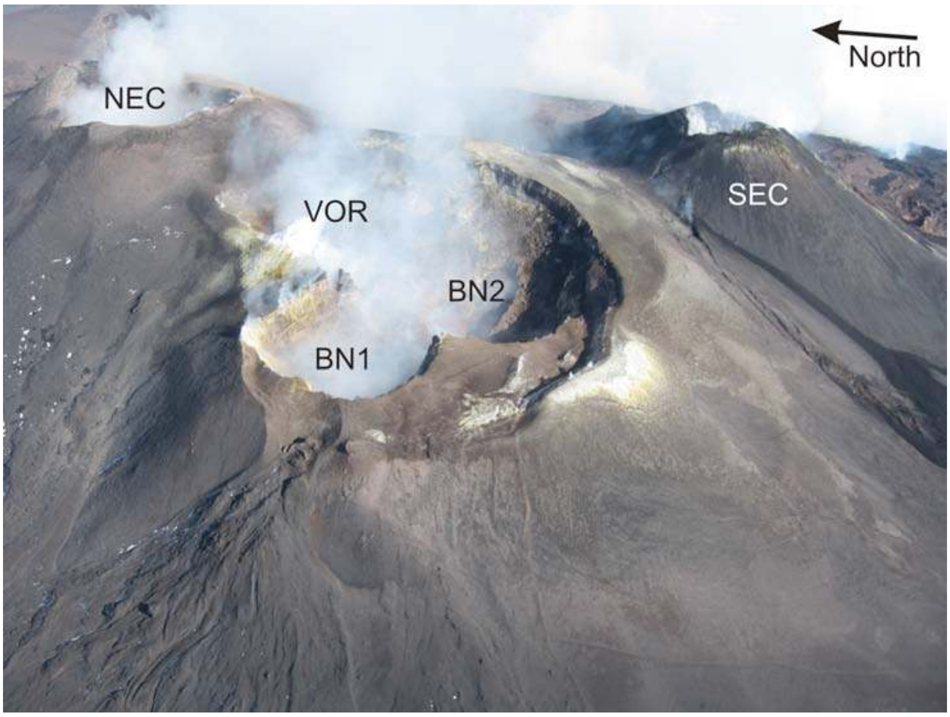

Figure 1 Summit Craters of Mount Etna: Bocca Nuova (BN1 and BN2),Voragine (VOR), Northeast Crater (NEC) and Southeast Crater (SEC).

1 Instruments background

1.1 FTIR instruments for emissivity measurements

In June 2007 spectra were collected with an OPAG-22 FTIR (Bruker Daltonics, Germany). The instrument weighs 19 kg and has dimensions of 37x40x26 cm (see Figure 1). The spectrometer collects spectra at up to 0.5 cm^{-1} resolution, using a ZnSe beamsplitter and LN_2-cooled MCT detector, over a wavenumber range from 500 to 6000 cm^{-1}. The field of view of the instrument is 30 mrad.

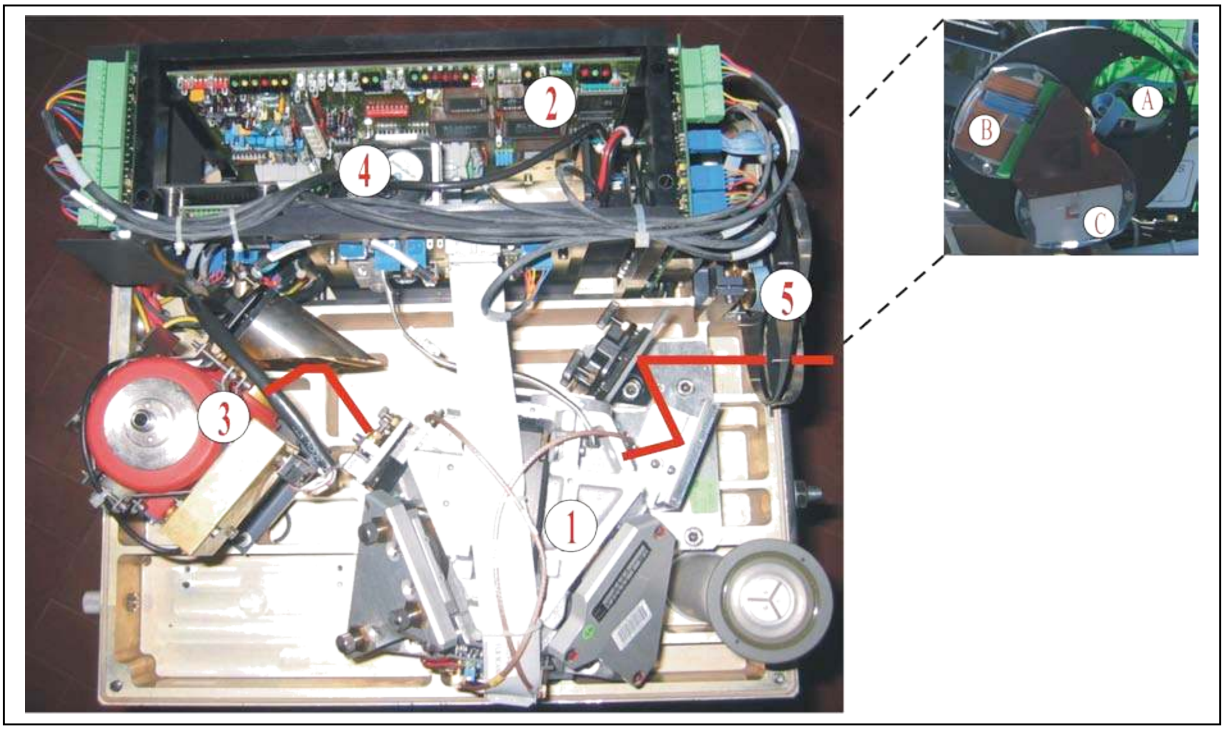

Figure 2 Optical layout of the Bruker OPAG-22 viewed from above, with inset highlighting the three apertures of the aperture wheel. In red the radiation path 1- Interferometer; 2- Elettronic; 3- Detector; 4- Laser HeNe. 5- Wheel A, B and C are the three openings.

Radiation enters the instrument through a wheel with three openings: A- open; B and C hot and cold black-bodies respectively. The wheel is controlled by software on a connected PC. In position A the instrument can be used to collect spectra, whereas B and C positions are used for instrument calibration during both tests and emissivity measurements. Input radiation, after reflection from two plane mirrors, passes through the interferometer block, which consists of two corner-cube reflectors on a pendulum mount. HeNe laser light from an internal source travels in parallel with the input radiation in order to measure the position of the moving mirrors. The output of the interferometer is a modulated signal measured with the detector. Interferograms are recorded on the hard disk of the PC and Bruker OPUS software allows conversion to absorption spectra, using a variety of apodization functions.

In order to determine emissivity of the radiation source, we have utilized the black-body to calibrate the spectrometer and then extracted the temperature of the surface by fitting a Planck curve to the calibrated spectrum. Using this temperature we produced an emissivity spectrum from the measured spectra.

In 2002/03 further FTIR measurements were collected on Etna with the objective of characterizing the emissivity of lava flows. The instrument used was the Model 102F spectrometer developed by Design and Prototypes for field measurements of Earth's surface and atmosphere spectral radiance. The spectrometer, called μFTIR (see Figure 3), operates at wavelengths ranging from 2 to 16 μm with a spectral resolution of 2 cm^{-1}. It has two liquid nitrogen cooled detectors, HgCdTe (or MCT) and InSb, for measurements collection in the 8-14 μm and 3-5 μm atmospheric windows respectively.

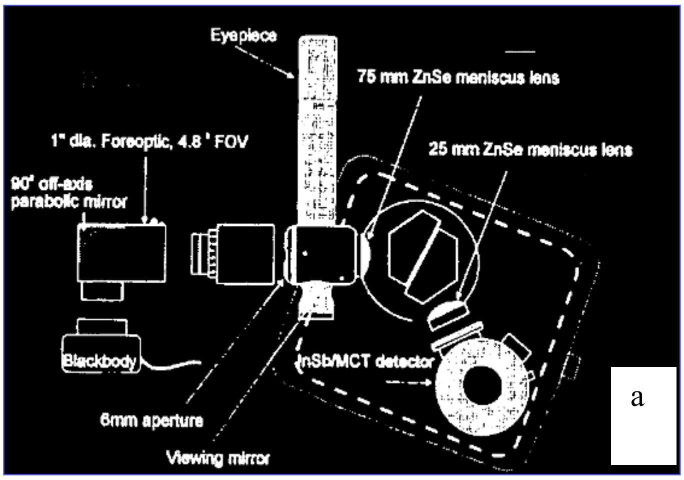

Figure 3 (a) Schematic diagram of the model 102F portable FTIR by Design & Prototypes, LTD; (b) Snapshot of the instrument.

This instrument was used on 2003 Mount Etna field campaign to measure emissivity.

The μFTIR software uses the following algorithm to compute the surface spectral emissivity:

$$\varepsilon(\lambda) = \frac{L(\lambda) - L_{DWR}(\lambda)}{L_{BB}(T_S, \lambda) - L_{DWR}(\lambda)} \quad (1)$$

where L(λ) is the spectral radiance field measured by the spectrometer, LDWR(λ) is the downwelling radiance field reflected from the sample into the spectrometer, LBB(TS,λ) is the spectral radiance field of a Black Body (BB) at temperature TS , ε(λ) is the target spectral emissivity. The downwelling radiance of the hemisphere above the target is measured with a golden plate reflector located on the target. A golden plate with emissivity ε = 0.040 on the instrument spectral range is provided with the μFTIR. Moreover the sample temperature T_S must be found by direct independent measurement .The instrument calibration is carried out by means of two blackbody measurements at two different temperatures. The measurement acquired data in the Pian del Lago area (Figure 4) during the 2003 campaign.

Figure 4 View from the helicopter of Pian del Lago area, partially covered by the 2001 eccentric cone.

1.2 The ASTER instrument

ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) is an international project funded by Japan's Ministry of Economy Trade and Industry and flying on NASA's TERRA satellite and launched in December 1999. The ASTER instrument has three separate optical subsystems: the visible and near-infrared (VNIR) radiometer, the shortwave-infrared (SWIR) radiometer, and the thermal infrared (TIR) radiometer [Pieri, D.C. and Abrams, M.J., 2004]. Table 1 summarizes the baseline performance of ASTER.

Characteristic	VNIR	SWIR	TIR
Spectral Range	Band 1: 0.52 - 0.60 µm Nadir looking	Band 4: 1.600 - 1.700 µm	Band 10: 8.125 - 8.475 µm
	Band 2: 0.63 - 0.69 µm Nadir looking	Band 5: 2.145 - 2.185 µm	Band 11: 8.475 - 8.825 µm
	Band 3: 0.76 - 0.86 µm Nadir looking	Band 6: 2.185 - 2.225 µm	Band 12: 8.925 - 9.275 µm
	Band 3: 0.76 - 0.86 µm Backward looking	Band 7: 2.235 - 2.285 µm	Band 13: 10.25 - 10.95 µm
		Band 8: 2.295 - 2.365 µm	Band 14: 10.95 - 11.65 µm
		Band 9: 2.360 - 2.430 µm	
Ground Resolution	15 m	30m	90m
Data Rate (Mbits/sec)	62	23	4.2
Cross-track Pointing (deg.)	±24	±8.55	±8.55
Cross-track Pointing (km)	±318	±116	±116
Swath Width (km)	60	60	60
Detector Type	Si	PtSi-Si	HgCdTe
Quantization (bits)	8	8	12

Table 1 Spectral and spatial characteristics of ASTER.

Reflected and emitted electromagnetic radiation from Earth's surface are detected and recorded by ASTER VNIR, SWIR and TIR sensors as raw instrument data. Data are calibrated, geometrically corrected and released as Level 1B data. These data are used to produce higher–level data products and are distributed by ASTER GDS (Ground Data System). Two surface reflectance products are available, one each for VNIR and SWIR. These products are atmospherically and topographically corrected basing on available climatological data and on global digital elevation data sets respectively [Gillespie, A. et al., 1998]. The data set are expressed in unitless reflectance; the percent reflectance can be derived from the product by multiplying each value by 0.001 [Bailey G.B., 2007].
The surface emissivity is obtained using the five atmospherically corrected TIR bands as derived from temperature/emissivity separation algorithm [Realmuto V.J, 1990]. The possible range of emissivity values between 0 and 1 are encoded as value between 0 and 1000 in the product.

On-demand **ASTER** acquisition was requested for June 19th 2007 with the objective of contemporaneously measuring satellite and ground-based data. In Figures 5 and 6 we show VNIR and TIR Mount Etna ASTER data acquired on July 2003 in the frame of a previous campaign and the data acquired on June 19th 2007.

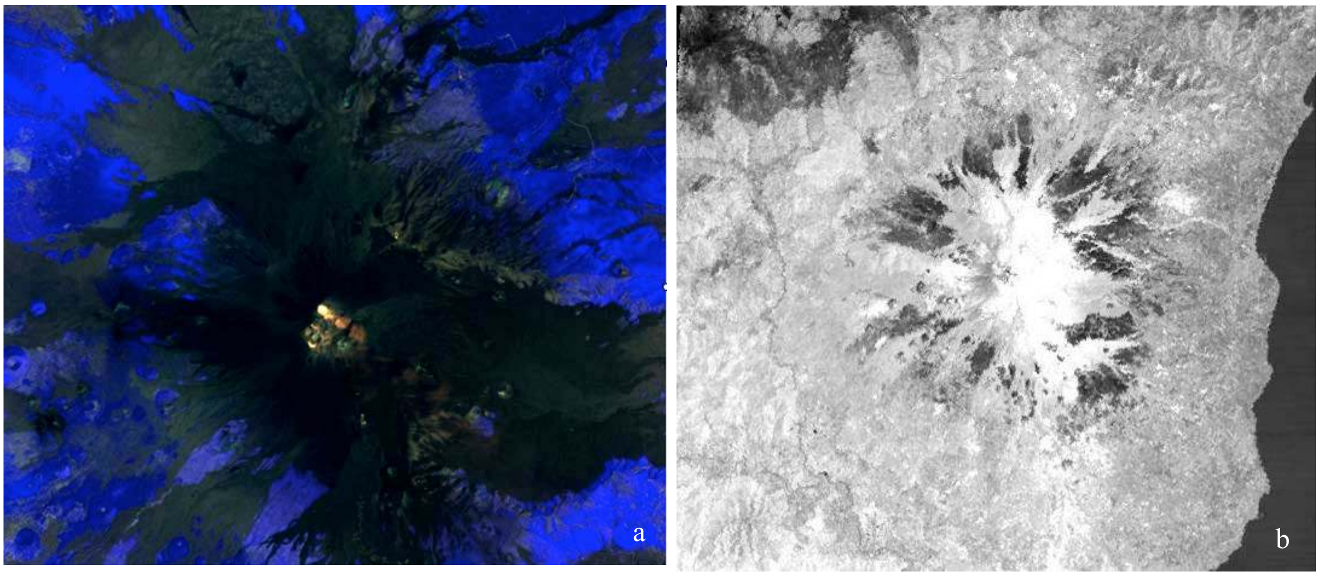

Figure 5 ASTER data acquired on July 19th 2003: (a) day Visible channels and (b) TIR channels during day acquisition.

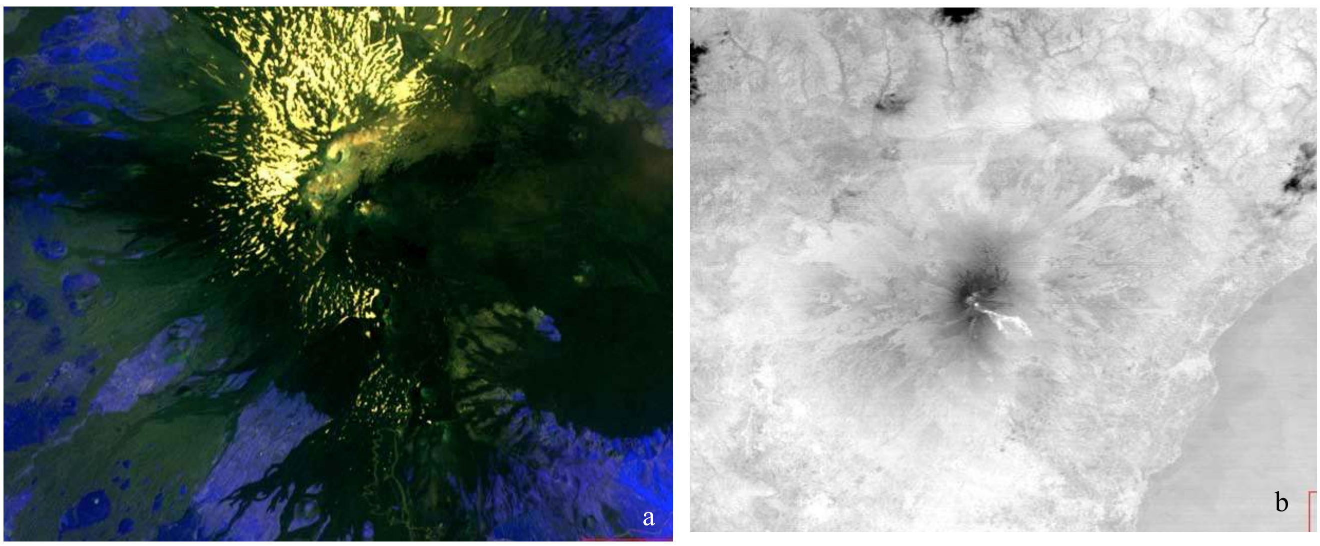

Figure 6 ASTER data acquired on June 19th 2007 (a) day 09:59 GMT and (b) TIR channels, night 21:03 GMT**.** The TIR data is interesting because shows the hot areas that interested the lava flow during 2006-2007 activity.

2 Campaign description

From 19th-23rd June 2007 a field campaign was carried out on Mt. Etna, Sicily, Italy with the objective of quantitatively characterising the spectral characteristics of some lava flows on the volcano during an on-demand overpass by the ASTER instrument, on board the NASA TERRA satellite. Spectral data in the visible, near-infrared and mid-infrared were acquired using three different instruments in order to constrain the emissivity of the surface over a wide wavelength range.

2.1 Test site description

A number of sites with different characteristics were chosen, which are believed to represent the great variety of recent volcanic surfaces that is encountered at Mt. Etna (Table 2). Normally there are two types of volcanic surface: lava flows and pyroclastic deposits.

In order to obtain a record as representative as possible, sites were chosen on lavas on different flanks and of different age, and with pyroclastic covers that show different characteristics. The locations of the measurement sites are shown in Figure 7.

2006-2007: intermittent summit activity concentrated in vents at and around the Southeast Crater. Lavas characterized by “aa” type morphology. In 2006 the eruptive activity affected mainly the eastern and western flanks of the Southeast Crater, producing long lived Strombolian eruptions, occasionally accompanied by lava emission from fissures opened at the base of the carter. The eruptive activity in 2007 consisted of several paroxysmal episodes with activity ranging from intense Strombolian explosions to lava fountaining, accompanied by lava outflow.

2002-2003: Second flank eruption characterized by the activation of the same two magmatic plumbing systems (central-lateral and eccentric) active in 2001. In this case the eruption was coupled with a major flank slip on the eastern and southeastern sides of the volcano. Lavas characterized by “aa” type morphology. A wide cover of pyroclastic products were emitted from the eccentric vents, which cover the Pian del Lago area.

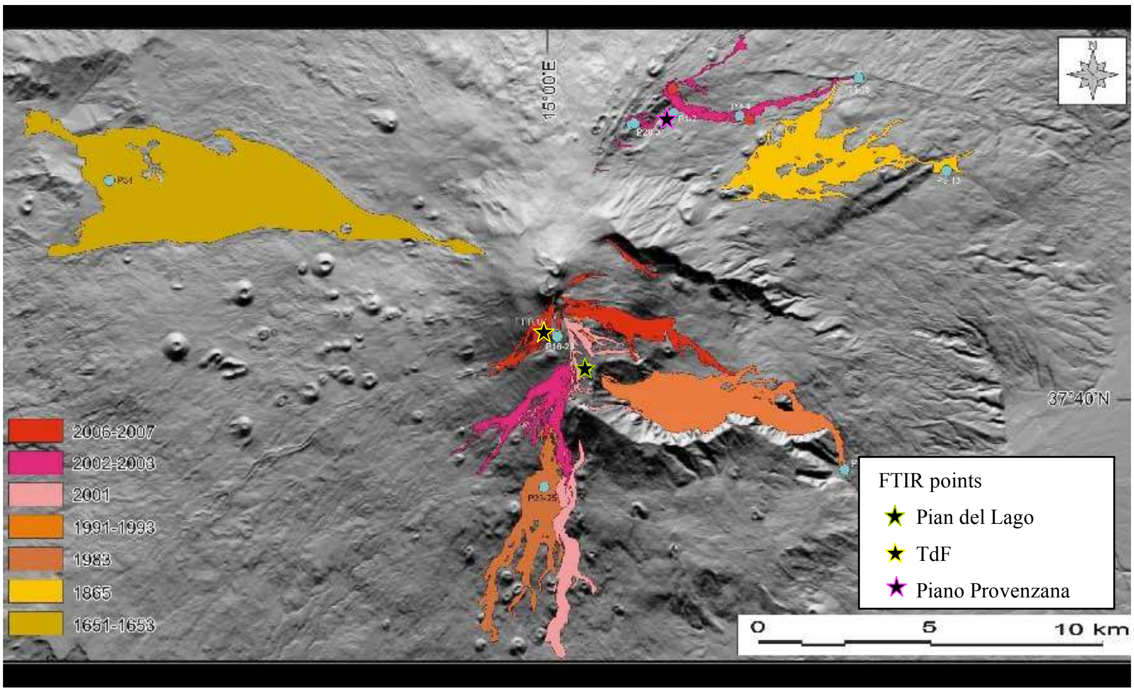

Figure 7 Historical Mount Etna lava Flows on DEM.

3 Preliminary results

The infrared (8-12 μm) spectral region has the minimum thermal emission from Earth and is positioned in a good atmospheric window. It is characterized by important absorption bands in emissivity spectra also for silicate and basalts that allows the study of a surface (Lythology). Measurements of emissivity realized on 2007 and 2003 [Amici et al.,2006; Amici et al. 2007] on three different points on Mount Etna have been compared with ASTER data (Table 2).

Site feature		FTIR 2003	FTIR 2007	ASTER 2003	ASTER 2007
Site name	Lava flow	Latitude Longitude	Latitude Longitude	Latitude Longitude	Latitude Longitude
Piana Provenzana (PP) Point 29	2002/03	-	N 37° 47' 40.56" E 15° 01' 24.42"	N 37° 47' 32" E 15° 01' 26"	N 37° 48' 16.51" E 15° 02' 24.7"
Pian del Lago (PDL)		N 37° 43' 42" E 15° 00' 30.6"	-	N 37° 43' 41.1" E 15° 00' 30.29"	N 37° 43' 22.5" E 15° 00' 25.63"
Ash Torre del Filosofo (TDF) Point 26	2006	-	N 37° 44' 18.66" E 14° 59' 54.60"	-	N 37° 44' 17.8" E 14° 59' 57.4"

Table 2 Test sites geo-location in situ and on satellite respectively.

3.1 Torre del Filosofo test site (ash and lava flow)

Torre del Filosofo test site is characterized by two different kind of surfaces: pyroclastic ash from 2006 Etna activity and lava flow from 2007 Etna eruption. Despite it was later spring time in the area were present some ice residual as shown in Figure 8.

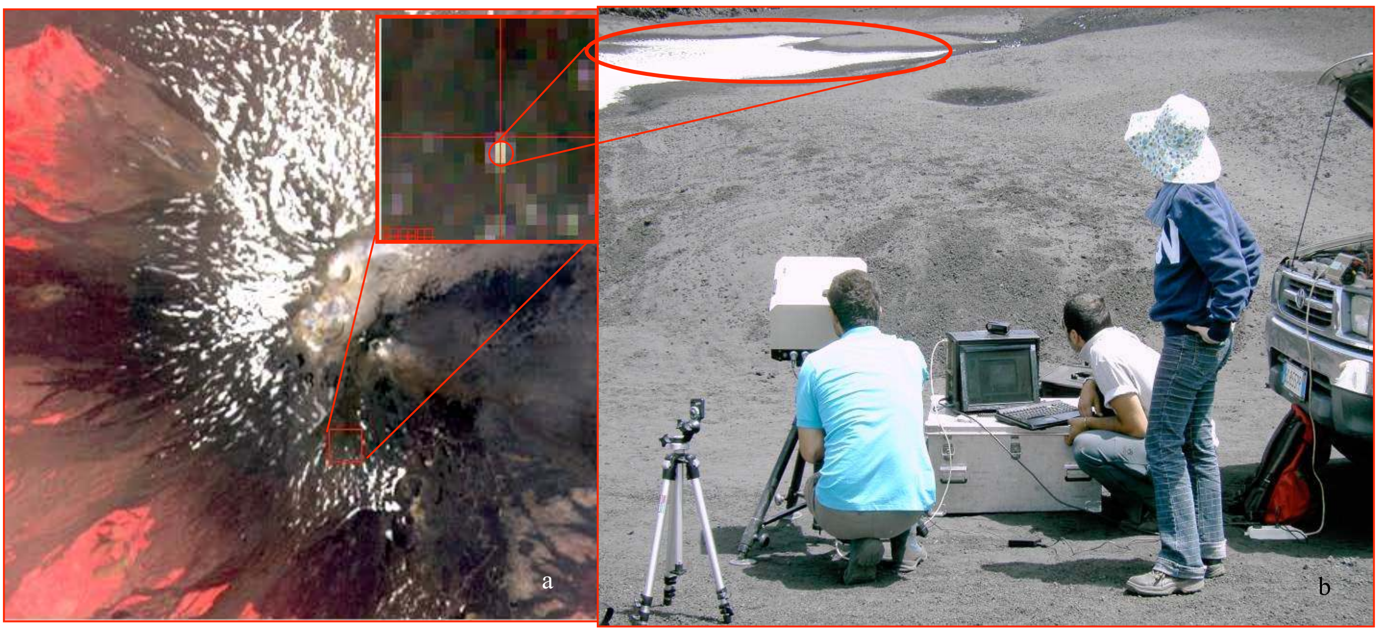

Figure 8 (a) Torre del Filosofo as seen by ASTER June 19th 2007 visible bands 15m spatial resolution and (b) the in field site characterized by FTIR.

Emissivity measurements were realized on Ash 2006 to ASTER emissivity data acquired on July 19th 2003 and on 19th June 2007. Due to the spatial resolution (90m) of the TIR band used for emissivity retrieval, the Aster emissivity is probably a mixture of the different components.
In Figure 9 is the plot of the emissivity of the two different kind of surfaces compared with ASTER data acquired on 2007.

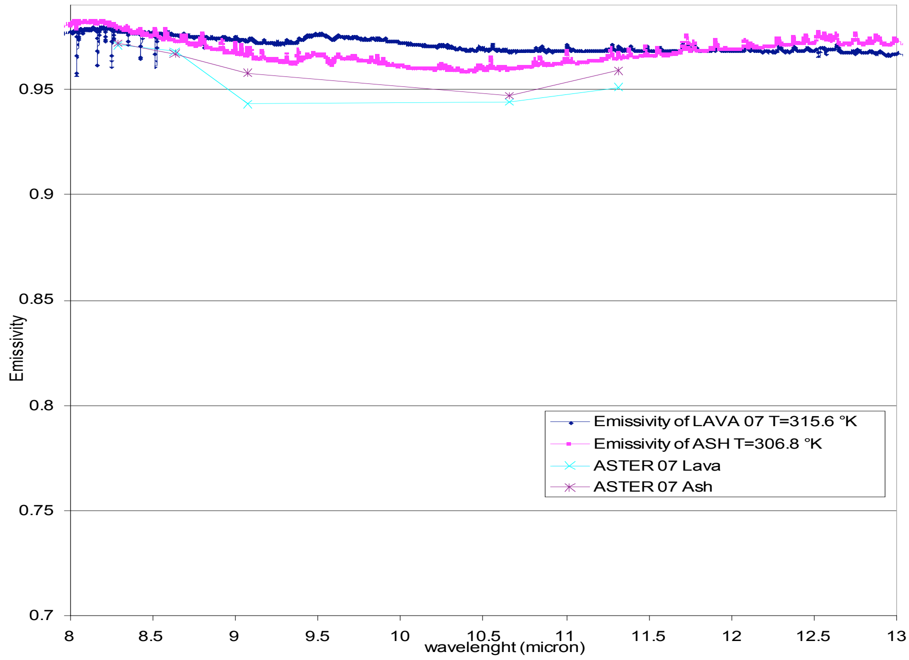

Figure 9 Torre del Filosofo N 37° 44' 18.66" E 14° 59' 54.20" Ash 2006 ; N 37° 44' 18.66" E 14° 59' 54.60" (lava 2007) ash and lava ground emissivity measurement are compared with the corresponding ASTER.

In Figure 10 the emissivity of Ash is compared with ASTER data acquired on 2003 and 2007.

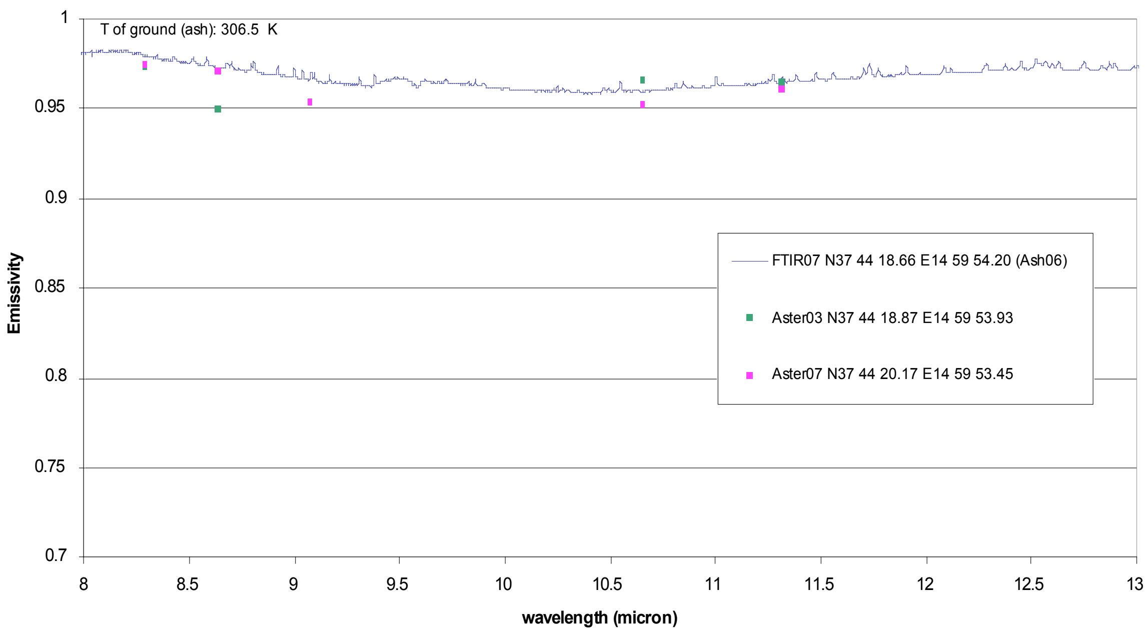

Figure 10 Torre del Filosofo N 37° 44' 18.66" E 14° 59' 54.20" Ash 2006. On ground emissivity measurement is compared with ASTER 2003 acquisition (green values) and ASTER 2007 (pink values).

3.2 Piana Provenzana test site

On ground emissivity spectrum was retrieved deriving the ground temperature by fitting the Plank function. The absorption bands can be due to the vibration in the silicon-oxygen group in amorphous groundmass (Figure 11).

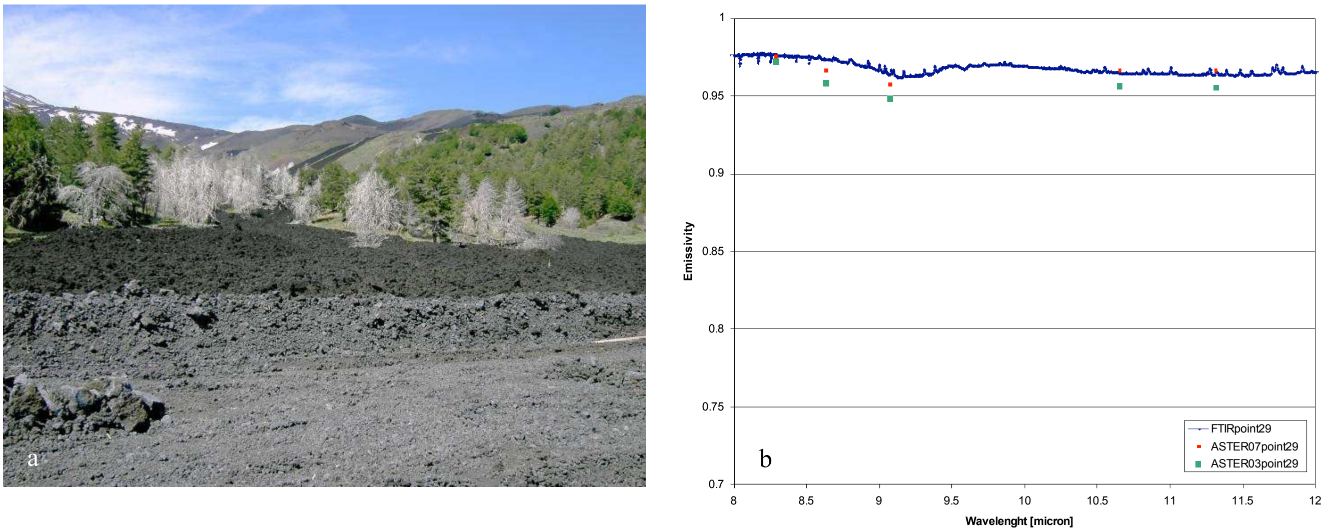

Figure 11 (a) N 37° 47' 40.56" E 15° 01' 24.42" corresponding to point 29 of Table 2 - Piana Provenzana area: (b) measured on ground emissivity on 2007 compared with ASTER 2007 same day (red) and ASTER 2003 (green).

3.3 Pian del Lago test site

Pian del Lago is a slightly tilted surface of cineritic scoria of centimeter range diameter located between the Valle del Bove scarp, the two new 2003 eruption craters and the 2001 eruption new crater on the southeast flank of the volcano.

The spectrum shows a clear, wide emissivity inflection at 10 micron, that can be attributed can be due to the vibration in the Al-O-Si group, possibly in plagioclase (Figure 12).

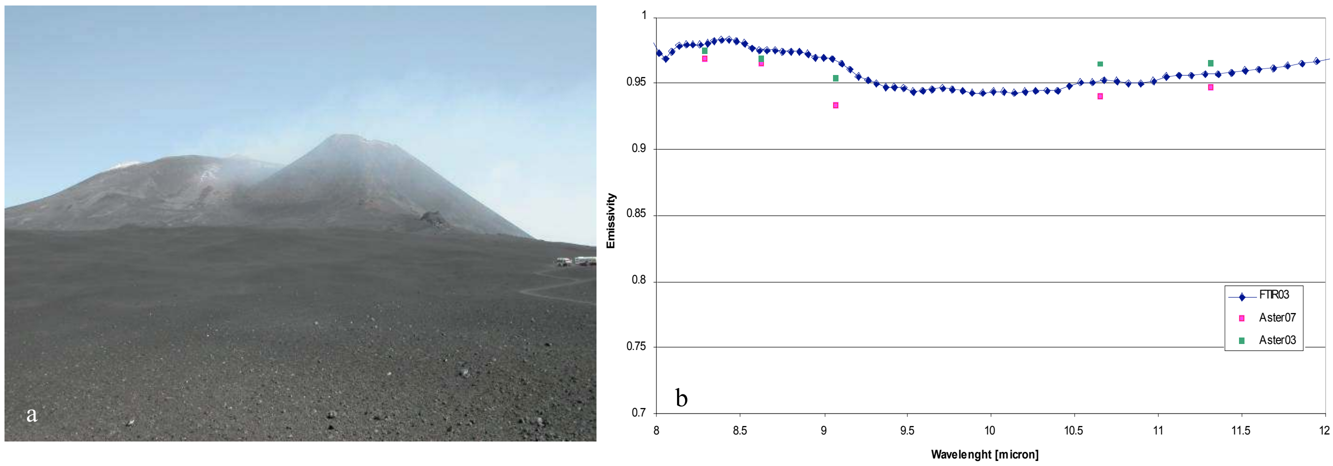

Figure 12 (a) N 37° 43' 42'' E 15° 00' 30.6'' is the point PDL of Table 2 and (b) measured on ground emissivity on 2003 compared with ASTER 2003 (green) and ASTER 2007 (red).

Conclusions

The in field campaign carried out on Mount Etna was devoted to the validation of satellite data.
In particular, in this technical note, we report the results obtained for the Nir-IR spectral range. Measurements obtained by FTIRs instruments was compared with standard products by ASTER sensor in the same spectral range.
A good agreement between the two kind of data was found for Piana Provenzana and Pain del Lago.
Future work will be devoted to understand the differences in the Torre del Filosofo test site: for instance planning a new series of in-situ measurements by using Micro FTIR and Bruker OPAG-22 jointly and cross calibrated. Geochemical analysis results of samples acquired in the test sites will be used to interpret the spectral features.
Further, ASTER radiance data will be processed applying local atmospheric profile for the atmospheric correction and the retrieved emissivity will be compared with ASTER standard data.

Acknowledgement

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