Ten years of EO data analysis on active volcanoes: Mt. Etna and Flegreian Fields (Naples)

M. F. Buongiorno[1], M. Silvestri[1], D. Pieri[2]

[1]Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy

[2]Jet Propulsion Laboratory, California Institute of Technology

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Summary

- Relevance of time series analysis
- Thermal pehomena scale
- ASTER TIR data analysis for Etna and Campi Flegrei volcanic areas
- Conclusions

Rationale and Relevance

The **I**stituto **N**azionale di **G**eofisica e **V**ulcanologia (INGV) has more than 20 years of experience in acquiring and processing Earth Observed (EO) data by spaceborne platforms.

In the last decade through ASI, ESA, EC, projects on integrated systems to support volcanic and seismic risk monitoring have been developed.

This work describes the results obtained by processing and analyzing ASTER time series for generating selected products which are functional to the different volcanic activity phases and respond to Operational requests

Volcanic thermal phenomena dimension and duration

HTE	Temperature K	Area m2/km2	Duration
Thermal anomaly (fumarole fields inside craters or on flanks)	283-360	10-10^2 m2	>> 1d
Lava flows	800-1500 core T 300-700 crust T	10^2-10^5 m2	>1d
Pyroclastic deposit	<1200	10^3-10^7 m2	>1d

SATELLITE AVAILABLE TO MEASURE VOLCANIC THERMAL PHENOMENA

Phenomena	Satellite Obs. technique	ORBITAL AND RESOLUTION CHARCTERISTICS	SATELLITES
HTE Lava flow thermal state characterization	LOW/Medium/HIGH resolution IR mapping	Geostationary IR satelites MIR/TIR	MSG GOES FY MTSAT
		POLAR MIR/IR 0,5-1 km res	AATSR MODIS AVHRR SENTINEL 3
		POLAR SWIR 30-100 m	LANDSAT ASTER HYPERION SENTINEL 2
L/M TE Pre-eruptive thermal anomaly	High resolution TIR mapping	POLAR TIR 30-100 m	LANDSAT series ASTER
		AIRBORNE 1-10 m	TIR SYSTEM OF DIFFERENT TYPE IN EACH COUNTRY

A large number of satellite data sets have been acquired in the frame of pilot monitoring system funded by the Italian Space Agency (ASI) in 2007-2011

FUNDING

AGENZIA SPAZIALE ITALIANA

PRIME CONTRACTOR

INGV

CONSORTIUM:

INGV, ACS, G-PLUS,CNR-IREA,UNIV-MODENA-REGGIO EMILIA

REFERENCE USERS

ITALIAN DEPARTMENT OF CIVIL PROTECTION

http://srv1.rm.ingv.it/srv/srv

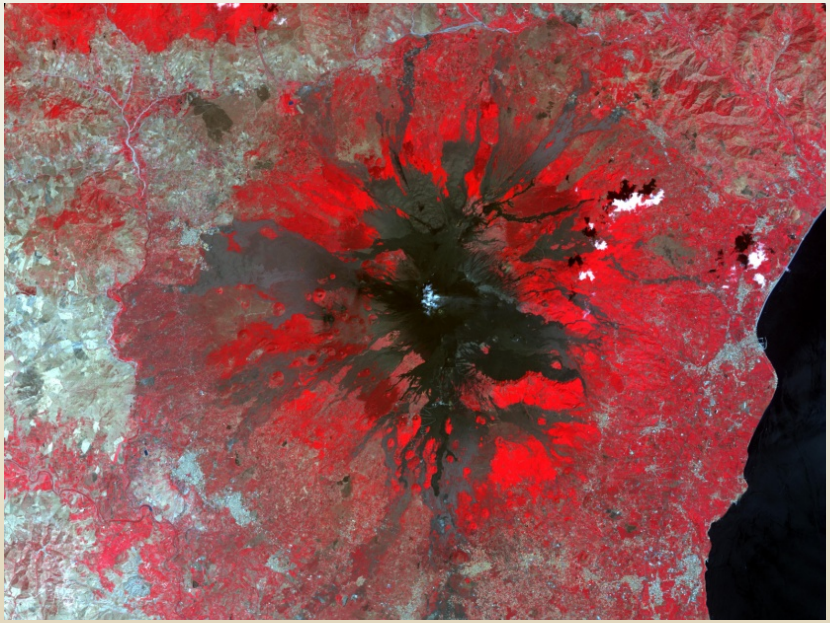
Products tested for each volcanic phases requested by DPC on test areas

DATA TYPE	SCHEDULING	ETNA	VESUVIO	CAMPI FLEGREI
GPS	Weekly (satellite passages)	X	X	X
Leveling	On availability base		X	X
SO2 (doas/cospec)	Continuosly	X		
Video Cameras	Every 15 minutes	X		
Geological observations	Periodically	X	X	X
Temperature	Based on Satellite passages			X
Geochemical (CO2)	Daily			X
Atmospheric profiles	Daily (3 times)	X	X	X

MT. Etna

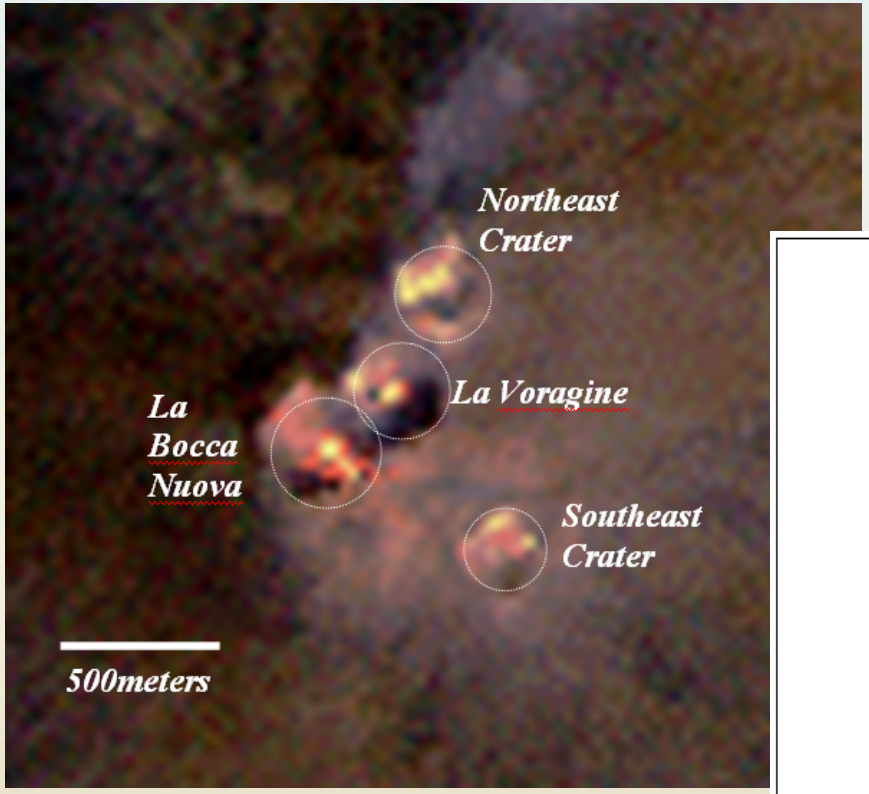
Mt Etna is the largest active volcano in Europe with a diameter of 40x40 kmq and elevation of abot 3350 m a.s.l. Towering above the city of Catania on the island of Sicily, it has been growing for about 500,000 years.

Mt Etna has the longest period of documented eruptions in the world. Etna is noted for the wide variety of eruption styles.

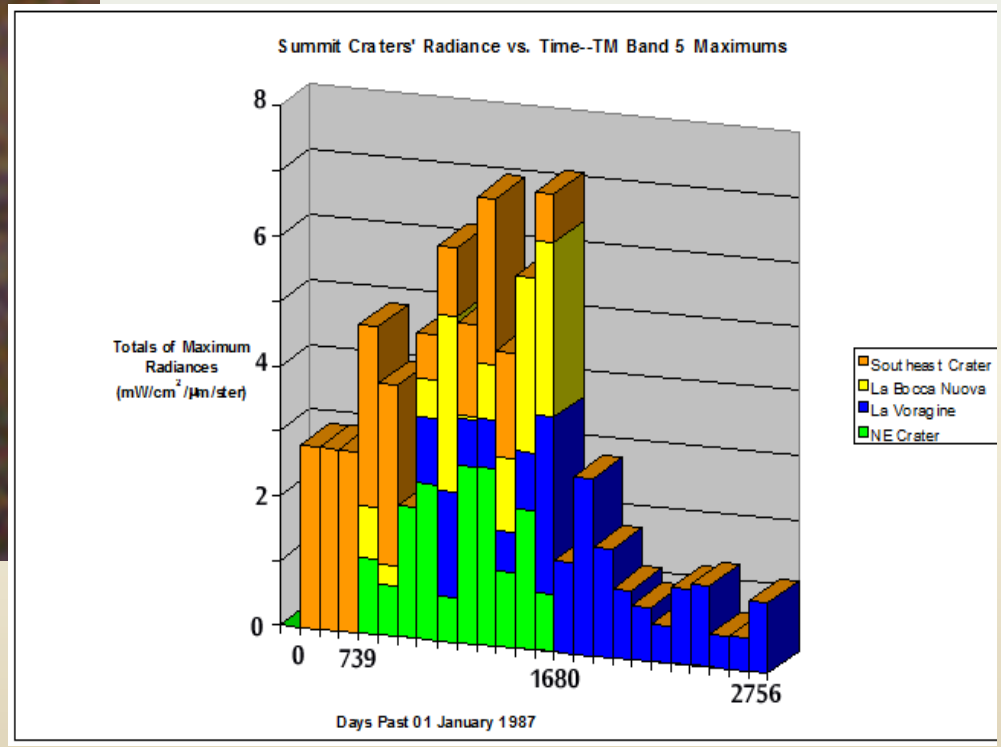


ASTER

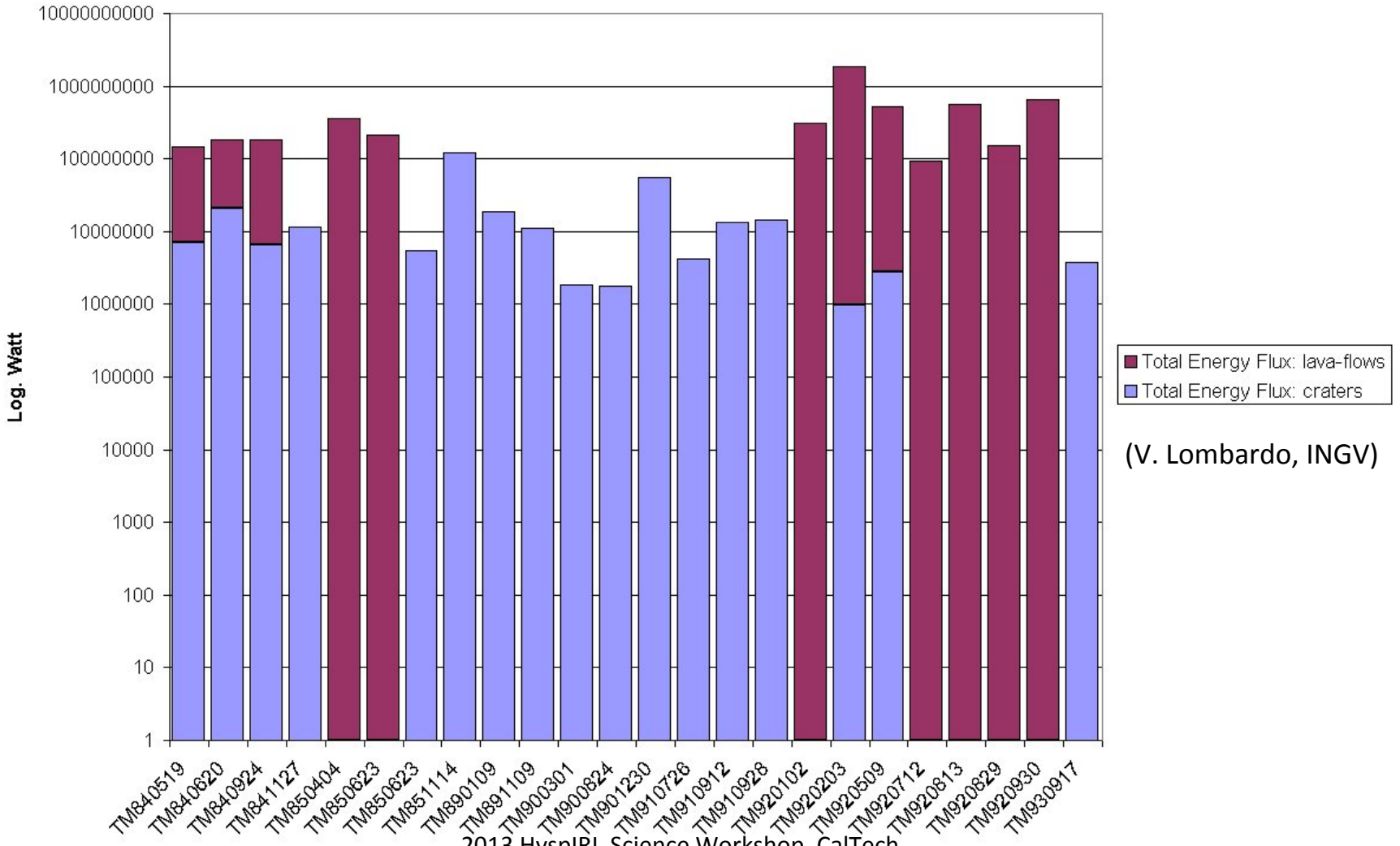
Etna is a very good laboratory volcano sicnce LANDSAT data have been acquired on Mt. Etna since 1984 and analysed by INGV and JPL teams (D.Pieri) .



analysis of summit radiation level



Thermal flux from LANDSAT data starting from 1984 to 1994



(V. Lombardo, INGV)

Thermal analysis of volcanoes: 10 years of ASTER data on Mt. Etna

The utilization of remote sensing techniques to understand the world's volcanoes is a focus of the world's major scientific agencies and space-faring countries

Results of the analysis of 10 years Mt Etna activity using TIR high spatial resolution data by means a semi-automatic procedure which extract the summit area radiance values with the goal of detecting variation related to eruptive events

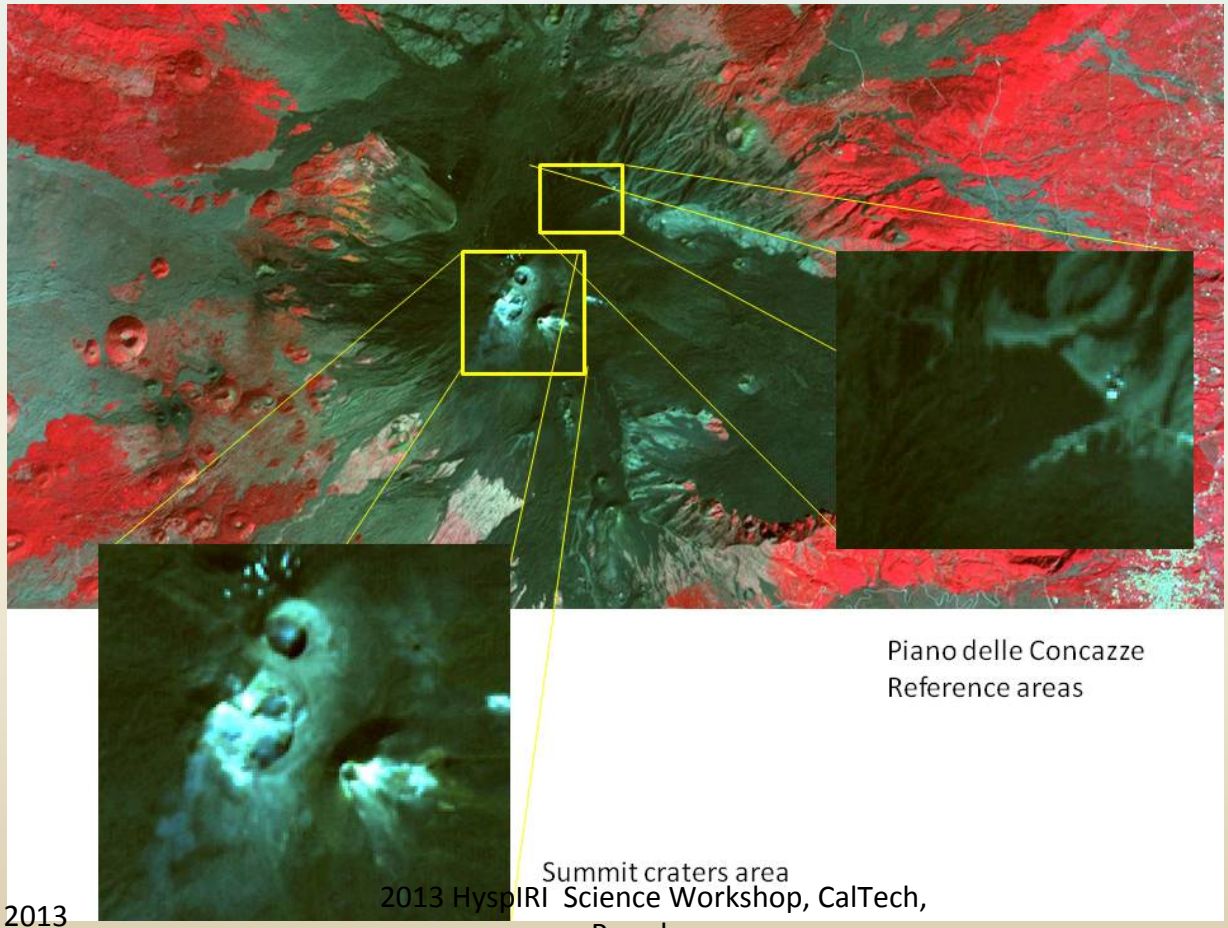
"Thermal analysis of volcanoes based on 10 years of ASTER data on Mt.Etna" - Maria Fabrizia Buongiorno, David Pieri, Malvina Silvestri published on Springer Thermal Infrared Remote Sensing - Remote Sensing and Digital Image Processing Volume 17, 2013, pp 409-428

Study area

Two areas have been considered:

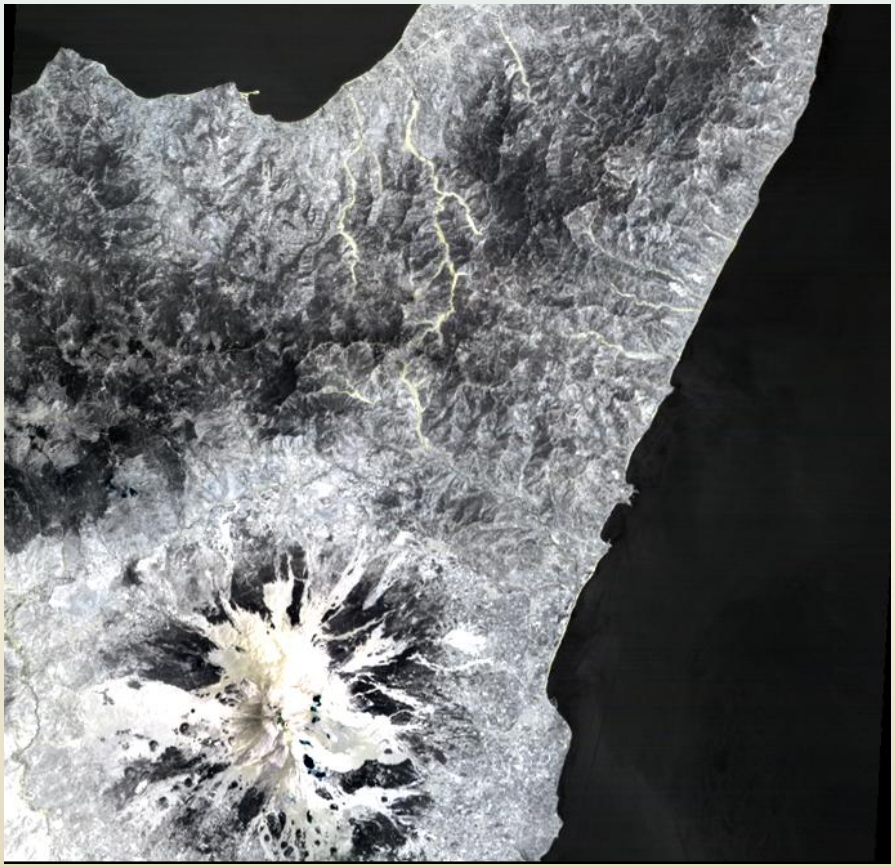
A - Mt. Etna summit crater thermal emissions in order to monitor and detect changes in the thermal emission during both quiescent and eruptive periods

B - "Piano delle Concazze" as a reference background since it is characterized by mineralogical homogeneous terrain composed of fine tephra and ash deposits.



ASTER (2002-2012) data sets on Etna and Campi Flegrei have been provided by a collaboration between INGV- NASA-JPL.

Campi Flegrei, Naples, Italy



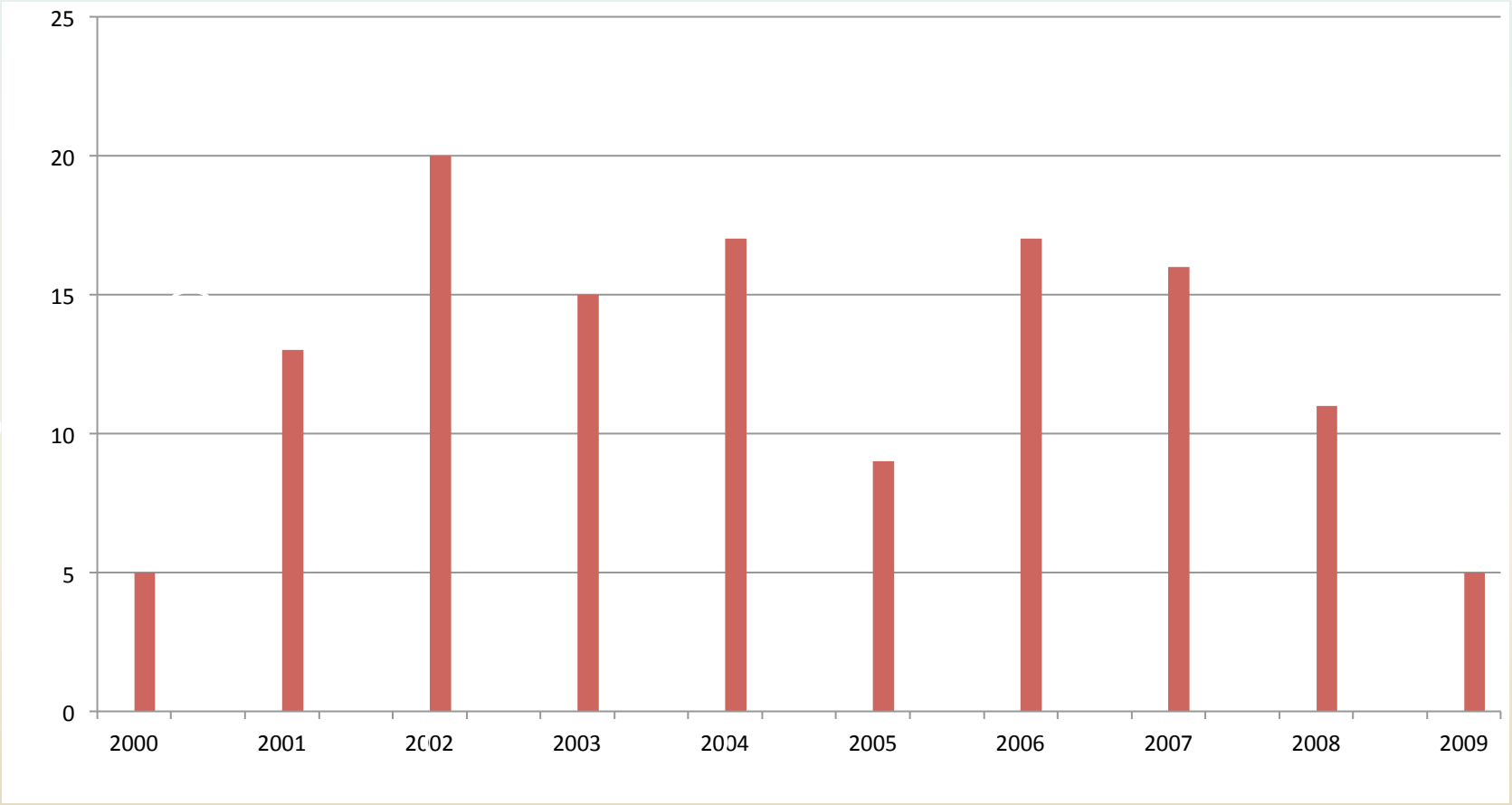
Mt. Etna, Sicily Italy

Aster data collection during 10 years, daytime and nighttime images and main eruptive events

Year	n. of ASTER images Daytime (about 10:00 UTC)	n. of ASTER images Nighttime (about 21:00 UTC)	Start Main eruptive events	Stop Main eruptive events
2000	4	3		
2001	4	13	17 July	9 August
2002	6	21	26 0ctober	
2003	13	12		23 January
2004	15	7	7 September	
2005	4	10		8 March
2006	8	13	14 July	15 December
2007	15	12	4 September 23 November	5 September 24 November
2008	9	5	13 May	
2009	4	7		4 July
2010	9	6	---	---

91 + 109 = **200** overall ASTER images

Mt Etna: ASTER data distribution between 2000-2009

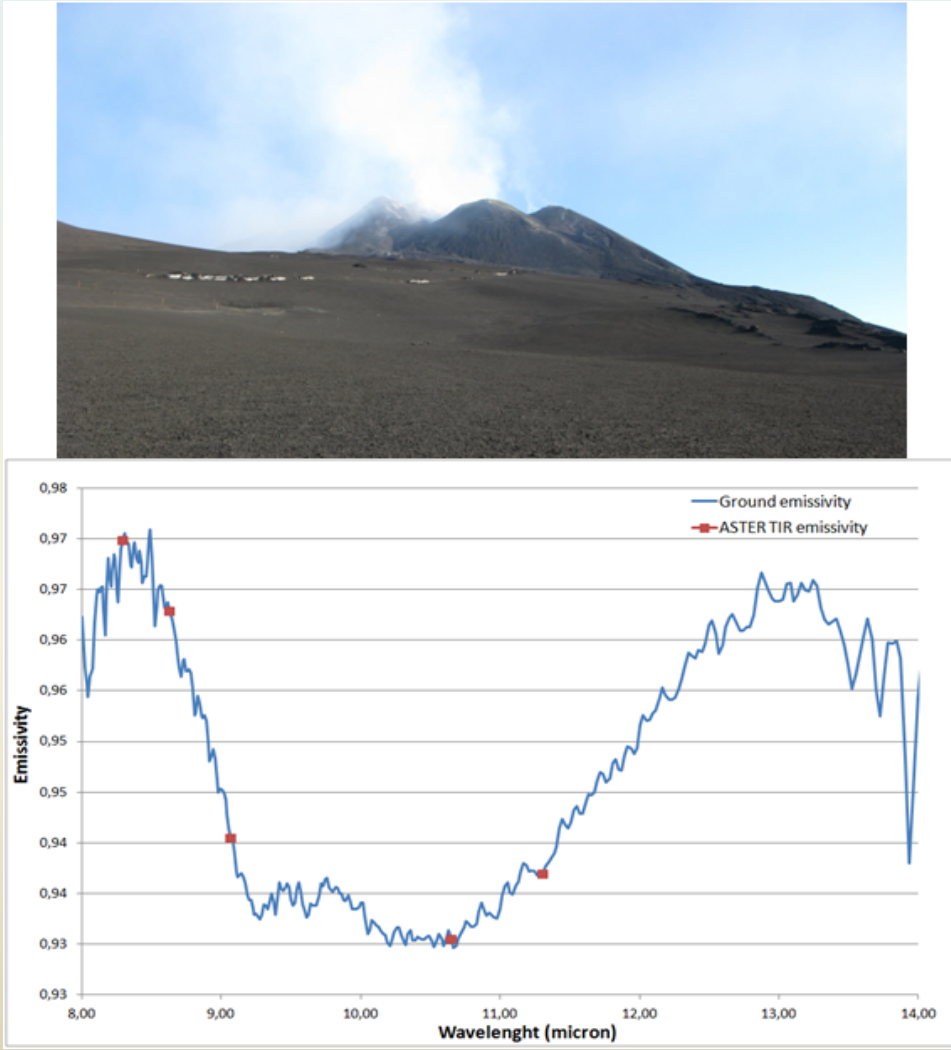


Processing steps:

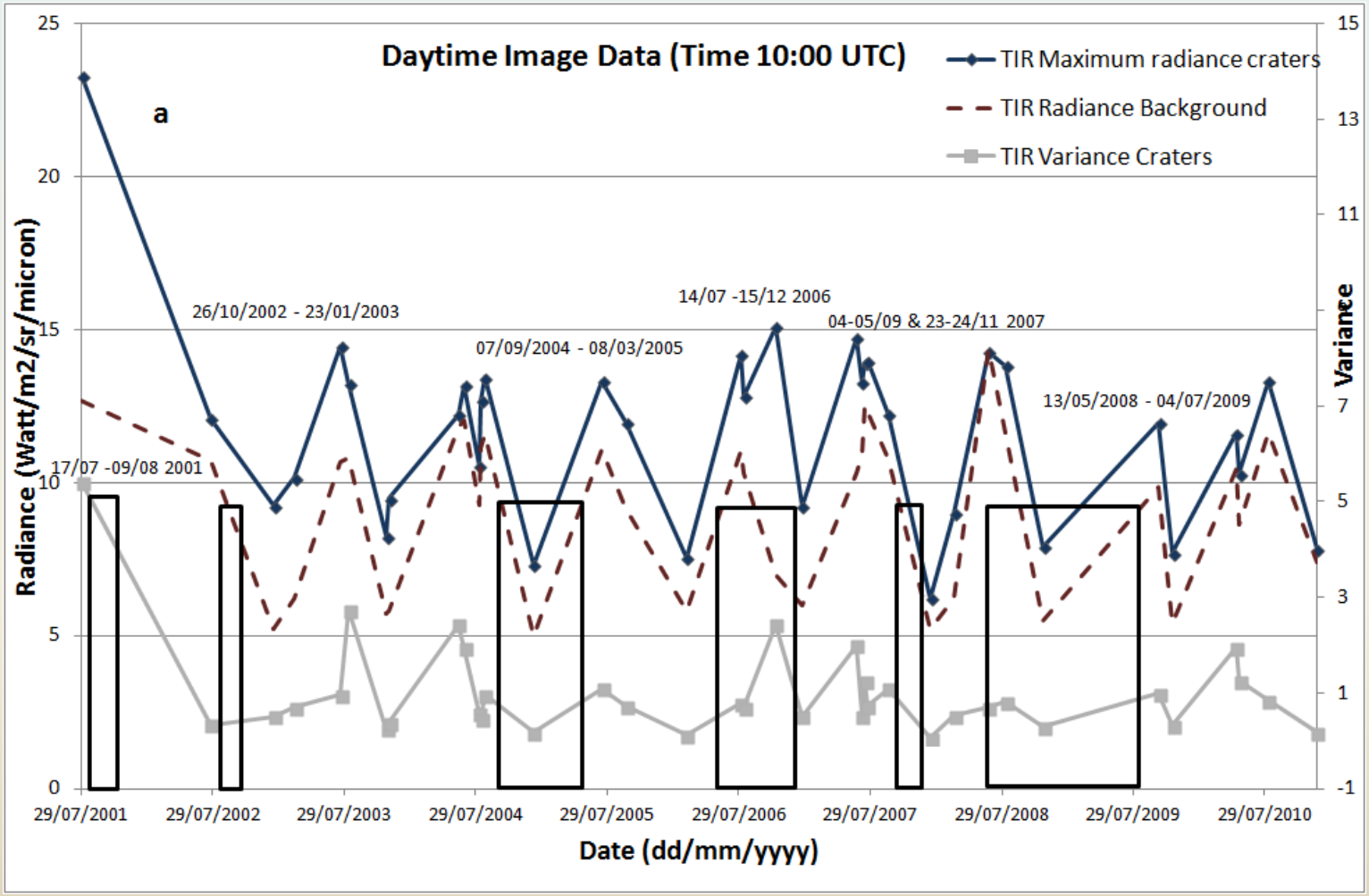
Infrequent repetition cycle of ASTER's and cloud occurrence have reduced the number of available ASTER observations for the assessments of volcanologically quiescent and active periods: **37** daytime and **65** nighttime cloud free ASTER images

For each data set, the **maximum radiance**, **mean radiance** and **variance** have been calculated using ASTER's TIR channel 4 (10.65 μm) that is not affected by SO_2 emissions.

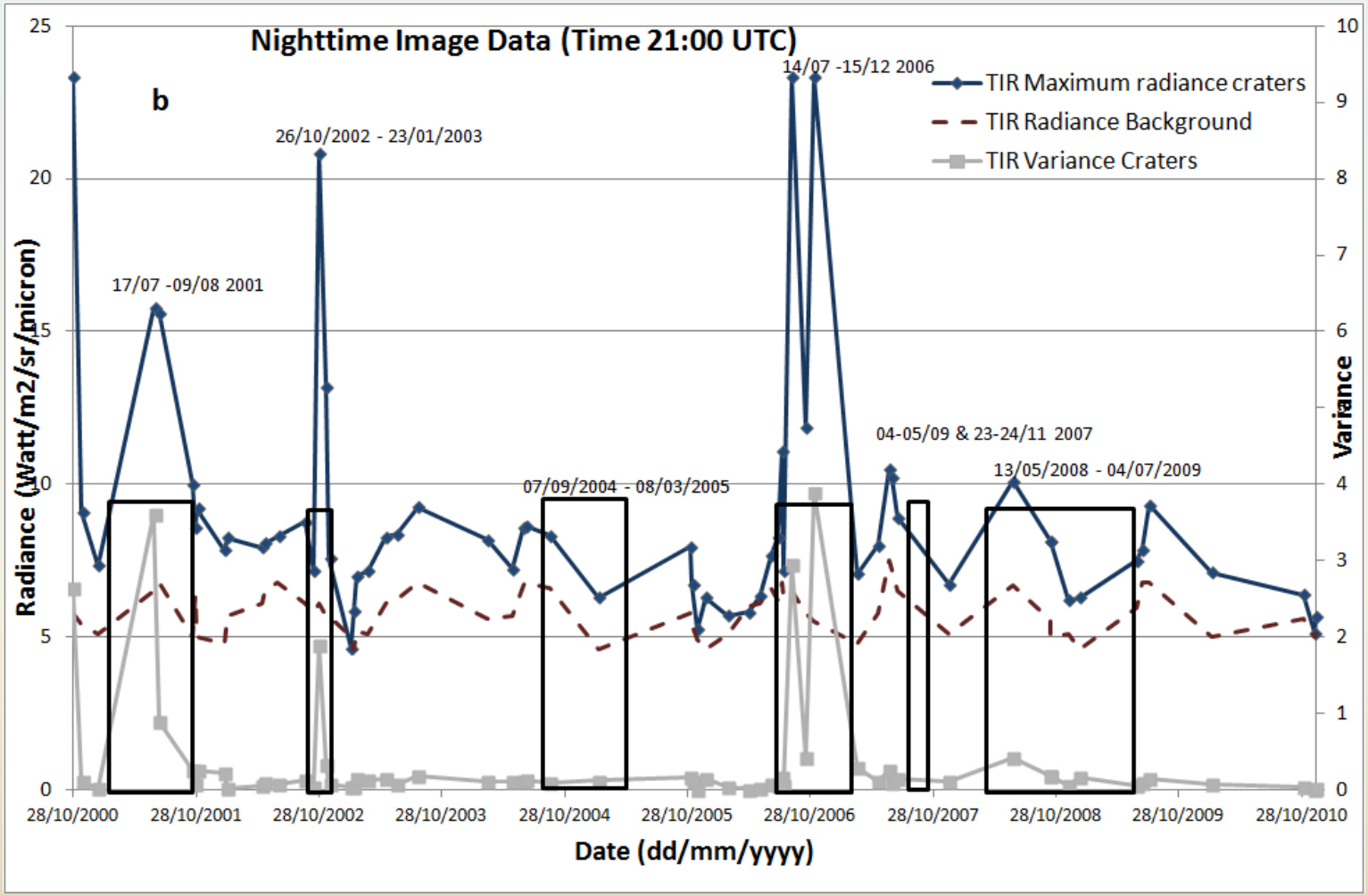
This channel has been utilized because of the high elevation of the site (e.g., over 3000m asl) and high emissivity in the selected TIR channel (e~0.95 as measured during field campaigns).



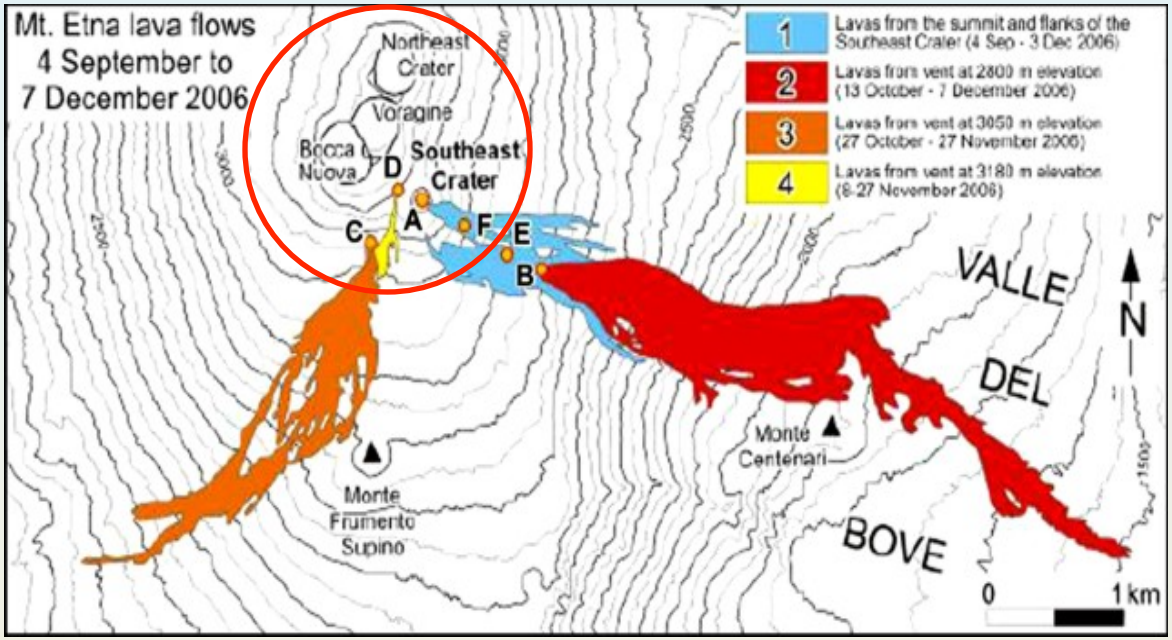
2000-2010 on Mt. Etna: Daytime data…

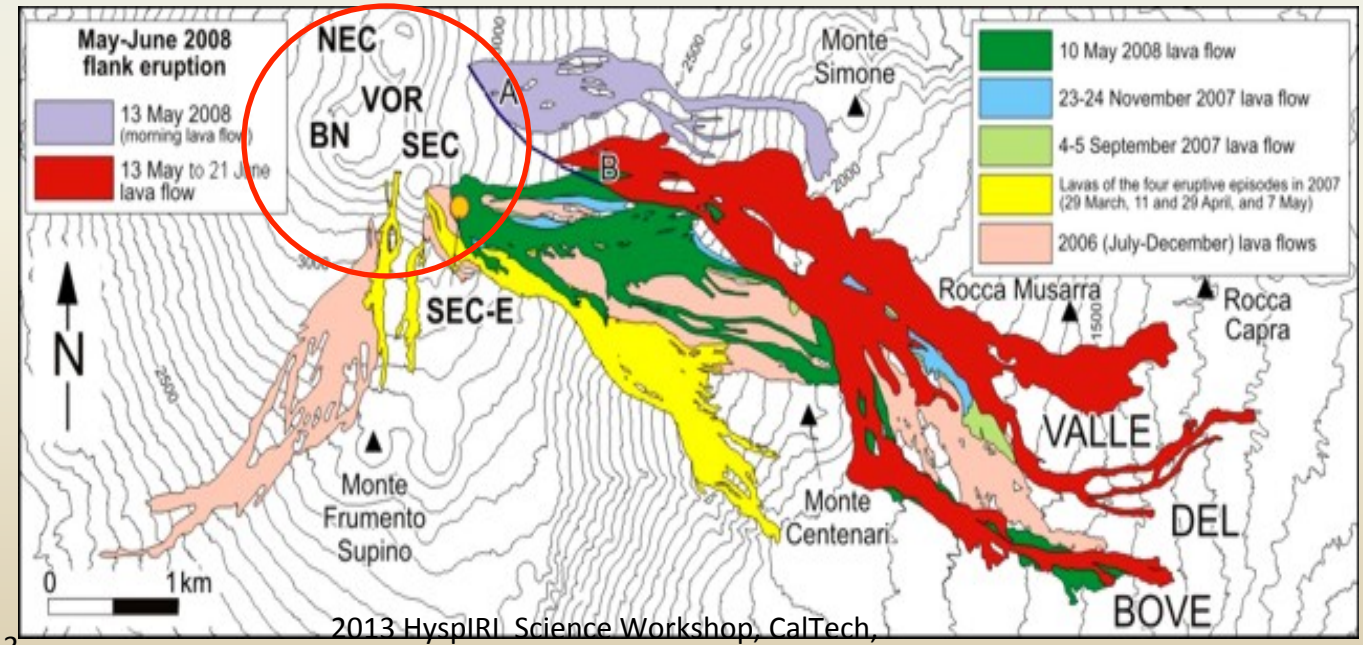


....Nightime data

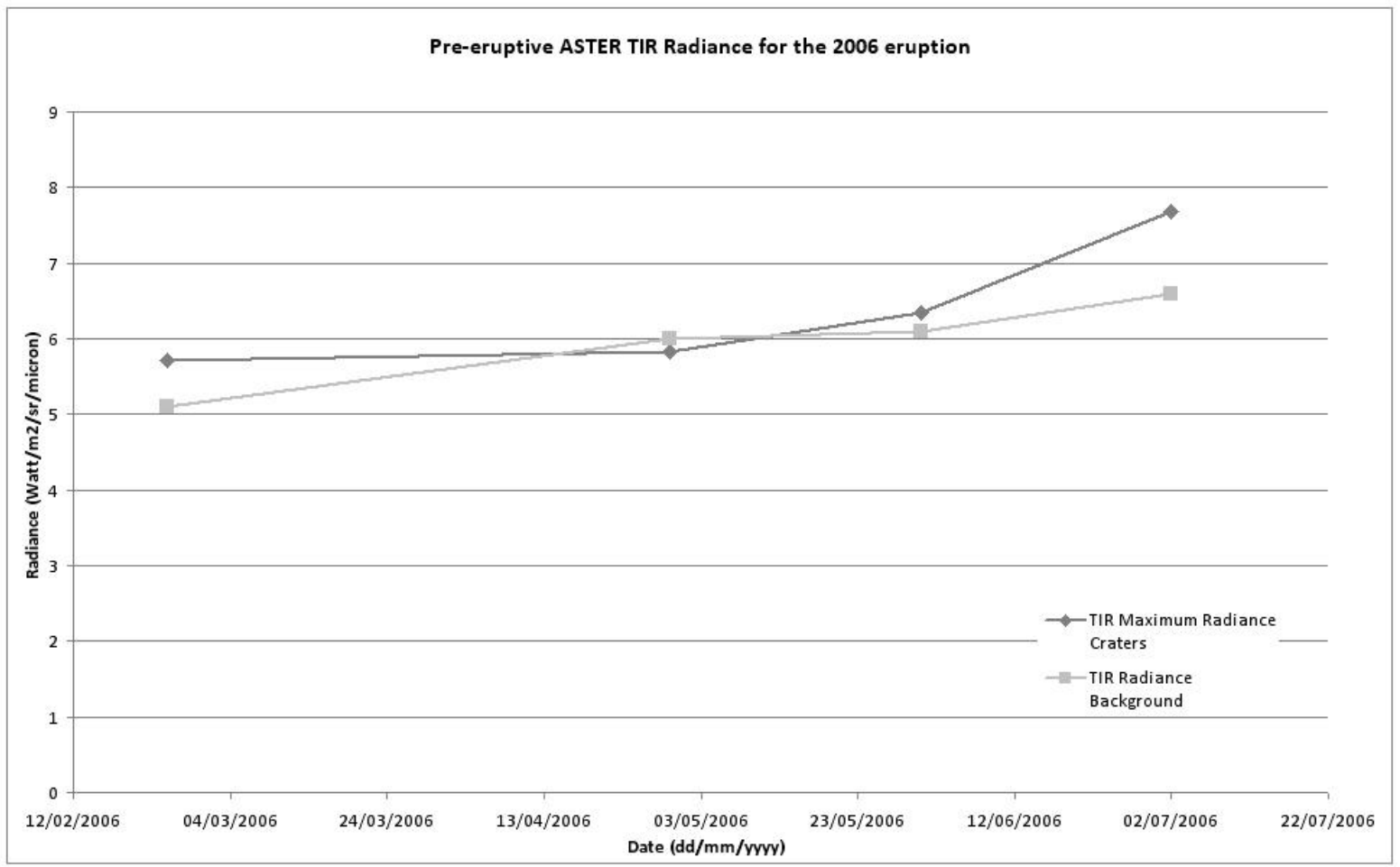


TIR data permit to detect changes in thermal emission which may be related to impending eruption


Mt. Etna lava flows
4 September to
7 December 2006
Northeast Crater
Voragine
Bocca Nuova
Southeast Crater
A
B
C
D
E
F
1 Lavas from the summit and flanks of the Southeast Crater (4 Sep - 3 Dec 2006)
2 Lavas from vent at 2800 m elevation (13 October - 7 December 2006)
3 Lavas from vent at 3050 m elevation (27 October - 27 November 2006)
4 Lavas from vent at 3180 m elevation (8-27 November 2006)
VALLE
DEL
BOVE
Monte Centenari
Monte Frumento Supino
N
0
1 km


May-June 2008 flank eruption
13 May 2008 (morning lava flow)
13 May to 21 June lava flow
NEC
VOR
BN
SEC
SEC-E
A
B
Monte Simone
10 May 2008 lava flow
23-24 November 2007 lava flow
4-5 September 2007 lava flow
Lavas of the four eruptive episodes in 2007 (29 March, 11 and 29 April, and 7 May)
2006 (July-December) lava flows
Rocca Musarra
Rocca Capra
VALLE
DEL
BOVE
Monte Centenari
Monte Frumento Supino
N
0
1km

Increasing Radiance at the summit craters has been detected

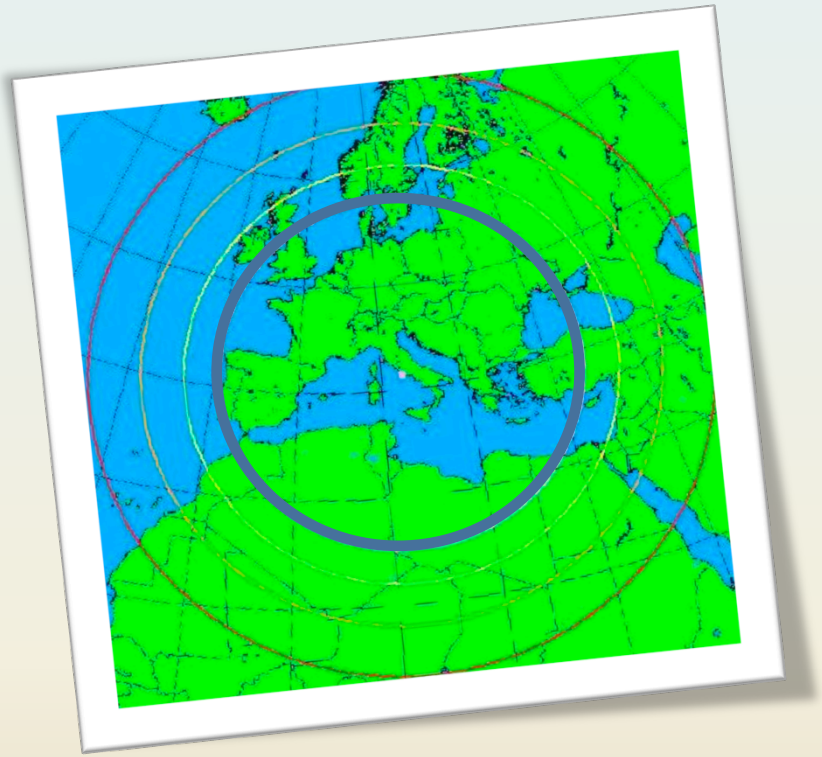


AVHRR data

AVHRR area: diameter 0.46 mt

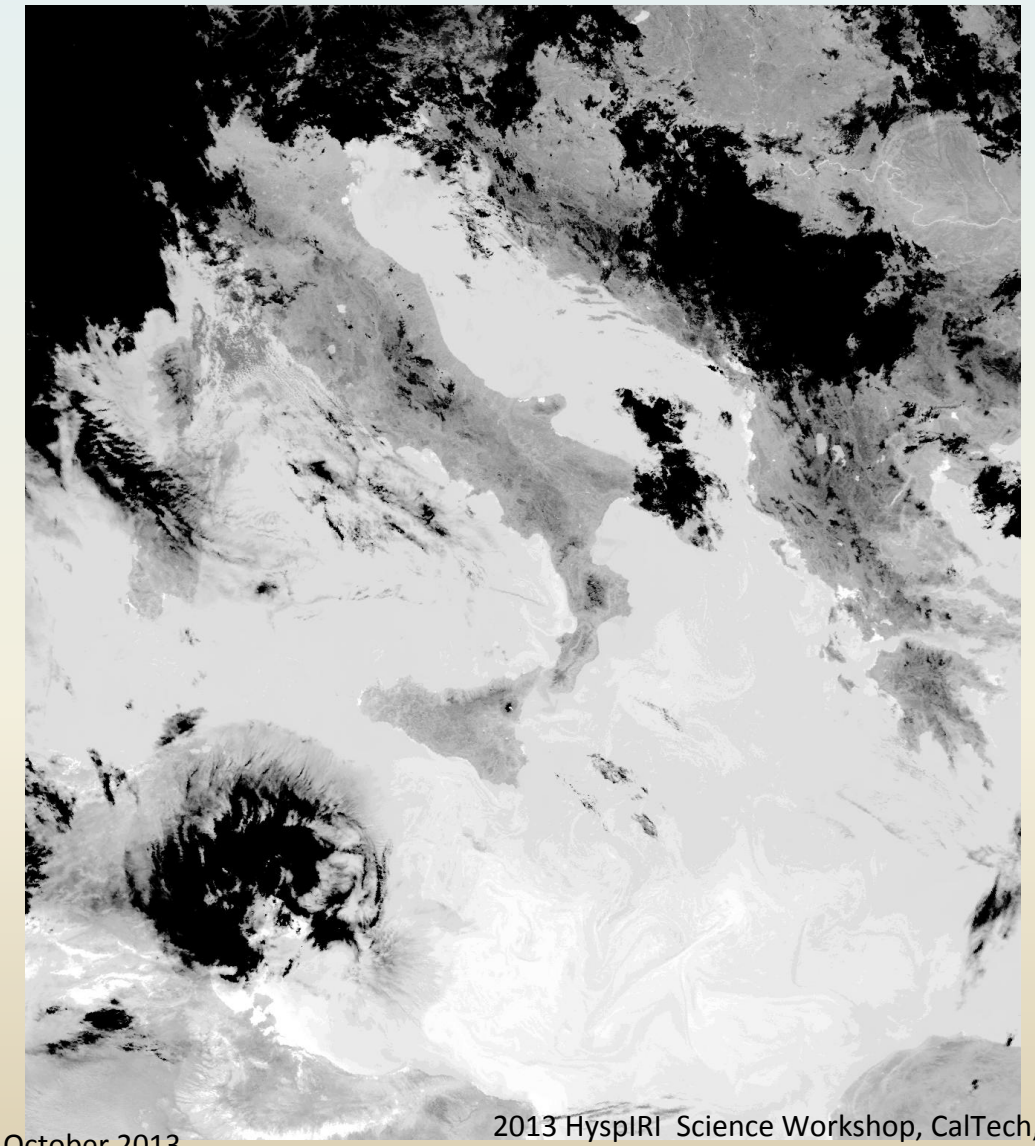
Acquisition: About 6 data/day

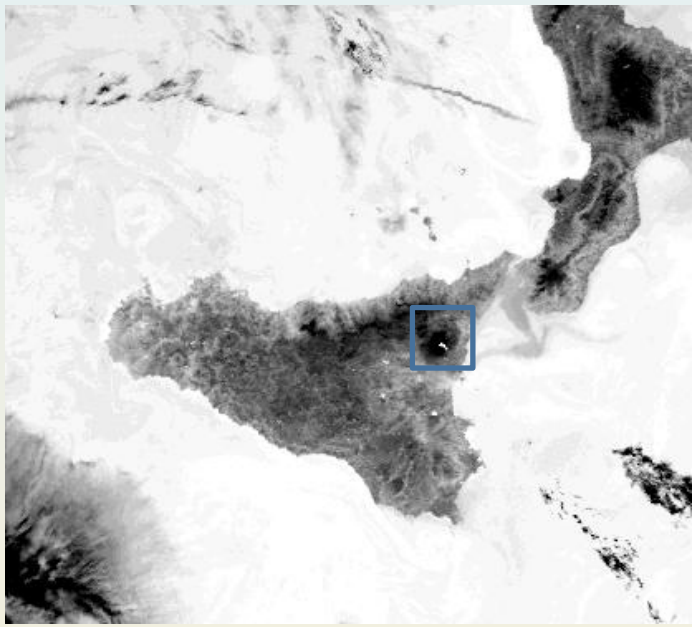
Nominal spatial resolution at Nadir: 1.1km

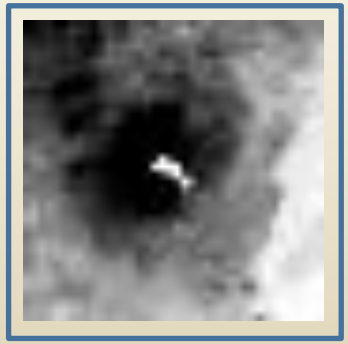


AVHRR	NOAA 12, 14	NOAA 15, 16, 17, 18, 19
Channel 1(VIS)	0.58-0.68 µm	0.58-0.68 µm
Channel 2 (NIR)	0.725-1.1 µm	0.725-1.1 µm
Channel 3A (MIR)	3.55-3.9 µm	3.55-3.9 µm
Channel 3B (MIR)	-	1.58-1.64 µm
Channel 4 (TIR)	10.3-11.3 µm	10.3-11.3 µm
Channel 5 (TIR)	11.4-12.4 µm	11.4-12.4 µm

AVHRR data

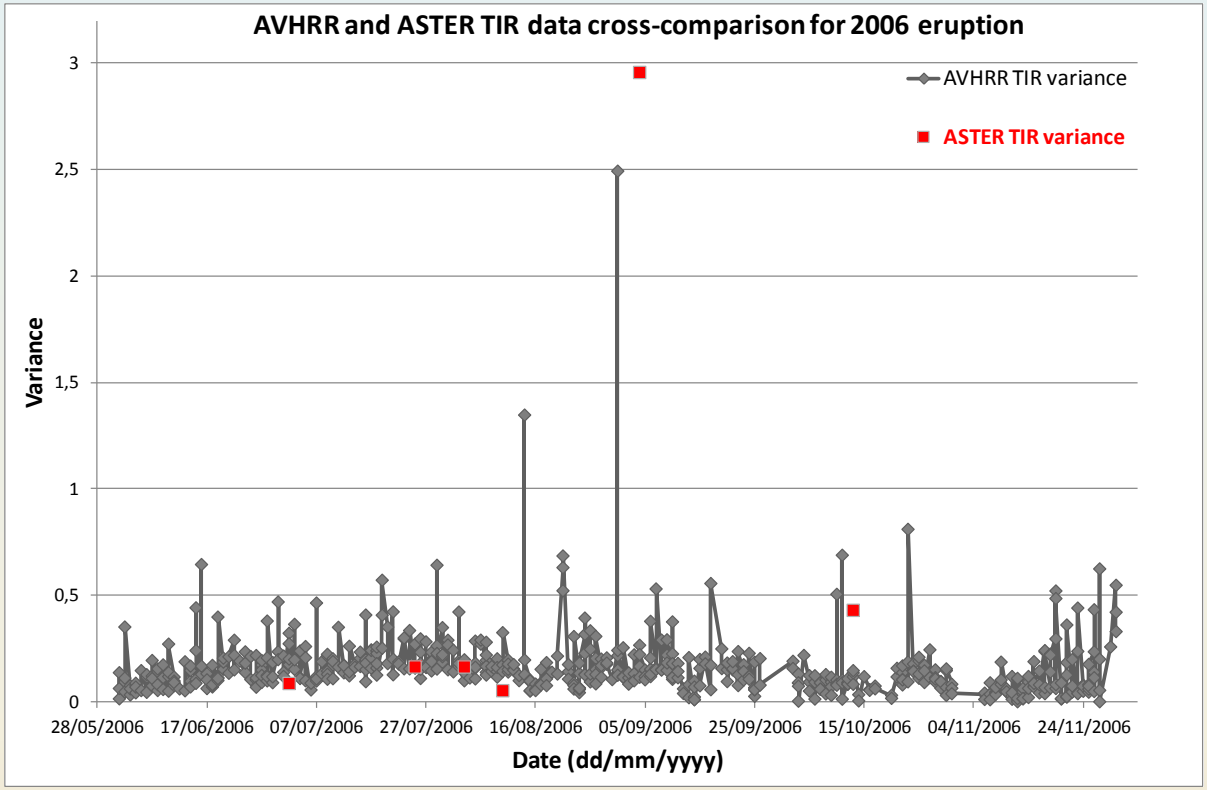






24th May 2008 00.58 UTC

ASTER and AVHRR comparison



Variance of the maximum ASTER TIR radiance during the 2006 eruption compared with the variance of the maximum AVHRR TIR radiance for the Mt. Etna summit area.

Despite the large difference in spatial resolution difference between the two sensors (ASTER=90 m/pixel, AVHRR=1000 m/pixel) and the dimension of the considered area which in AVHRR case covers all the summit part of Mt. Etna structure, there is a good correlation in terms of trend and values between the two data sets.

Consideration on Mt. Etna

ASTER data show a higher variance of maximum radiance values than AVHRR data due to the presence of active lava flows.

The lower spatial resolution of the AVHRR pixels dilutes and smoothes the contribution of emitting pixels in the variance of the radiant intensity, which is resolved at over two orders of magnitude greater in the ASTER TIR data.

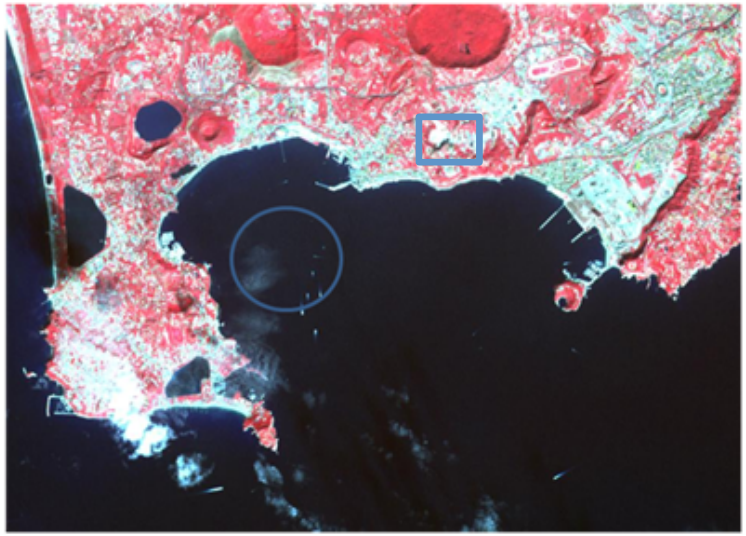
Even if this comparison shows that AVHRR sensor provides the frequency necessary to detect the onset of large thermal anomalies, its low spatial resolution allows to detect only high intensity thermal anomalies;
to further exploit small thermal variation in open conduit volcanoes it is necessary to have at least 90 meter resolution as ASTER but due cloud coverage the revisit time is a very important factor.

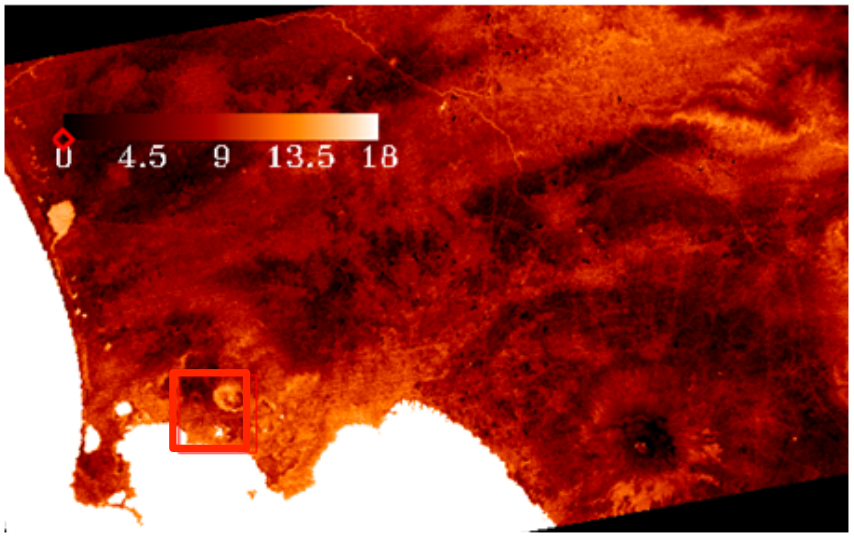
CAMPI FLEGREI AREA

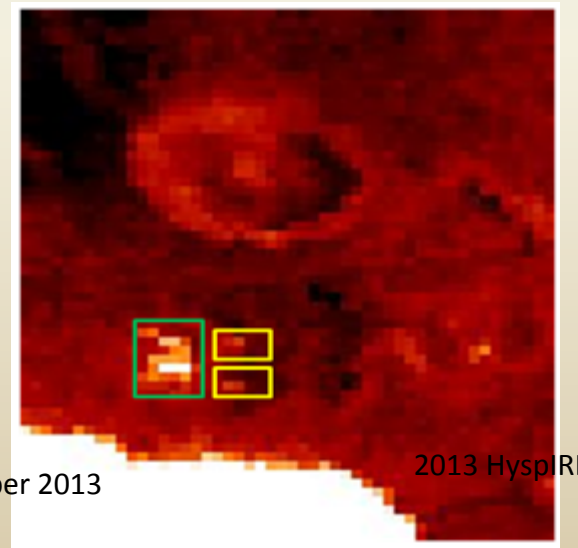
- The earliest known eruptive products are dated 47,000 years before present (BP). The Campi Flegrei caldera formed following two large explosive eruptions, the massive Campanian ignimbrite about 36,000 years BP, and the >40 cu km Neapolitan Yellow Tuff (NYT) about 15,000 years BP. Following eruption of the NYT a large number of eruptions have taken place from widely scattered subaerial and submarine vents. Most activity occurred during three intervals: 15,000-9500, 8600-8200, and 4800-3800 years BP. Two eruptions have occurred in historical time, one in 1158 at Solfatara and the other in 1538 that formed the Monte Nuovo cinder cone.

SOLFATARA

10 years on Flegreian Fields ("Solfatara", Naples): 2002-2013







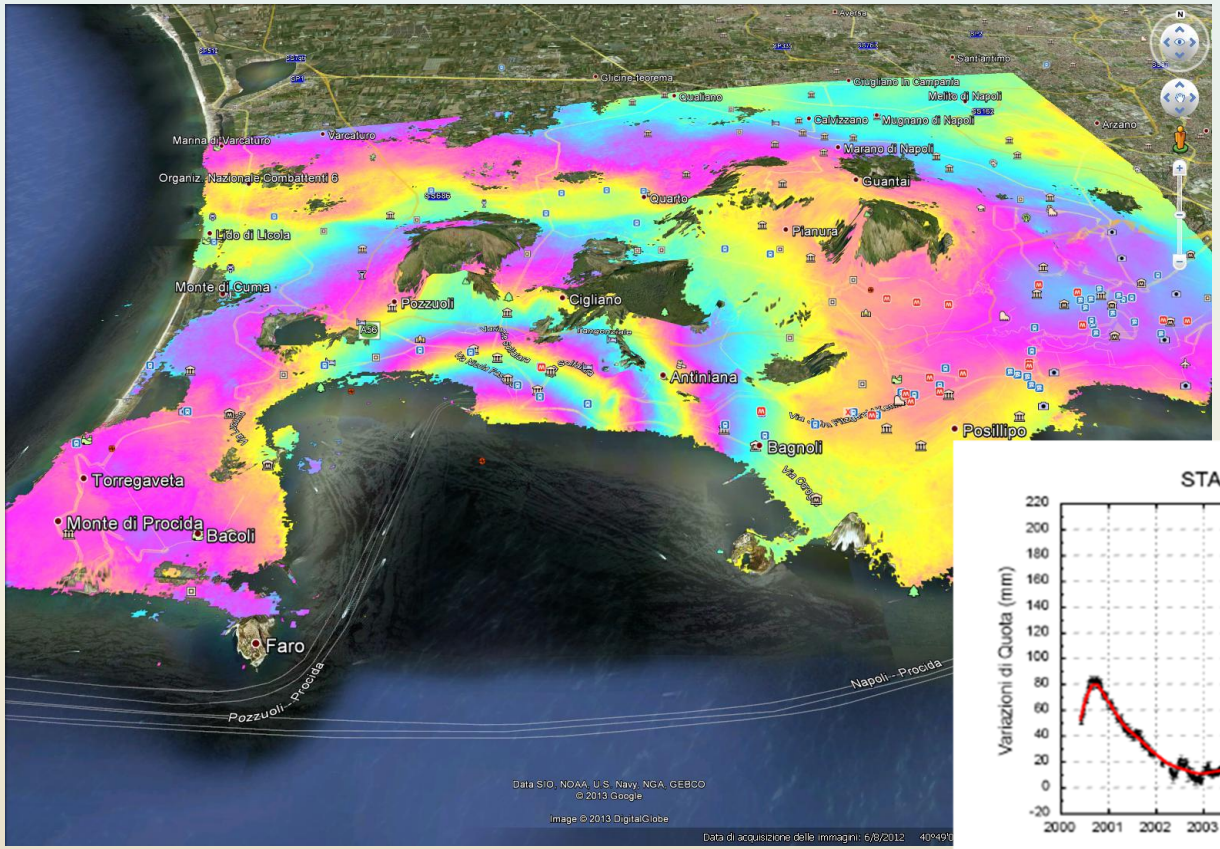
27 nighttime cloud free ASTER images on Solfatara area have been selected in order to detect thermal anomalies, if present.

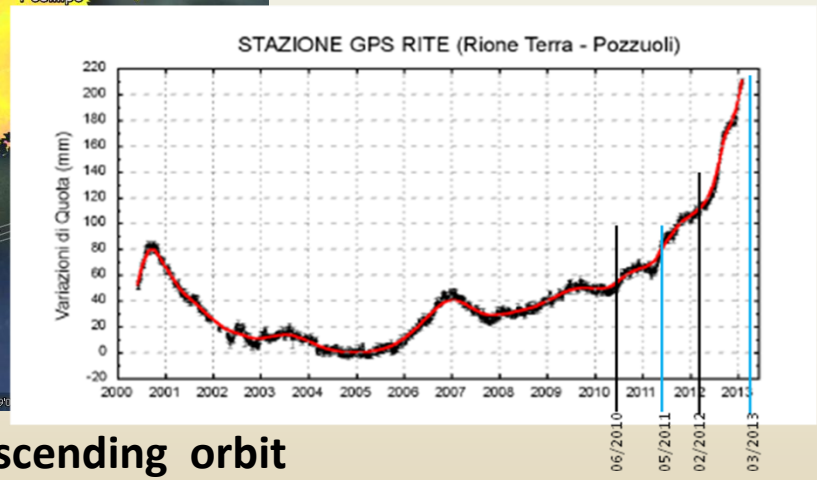
Solfatara area

Pisciarelli area

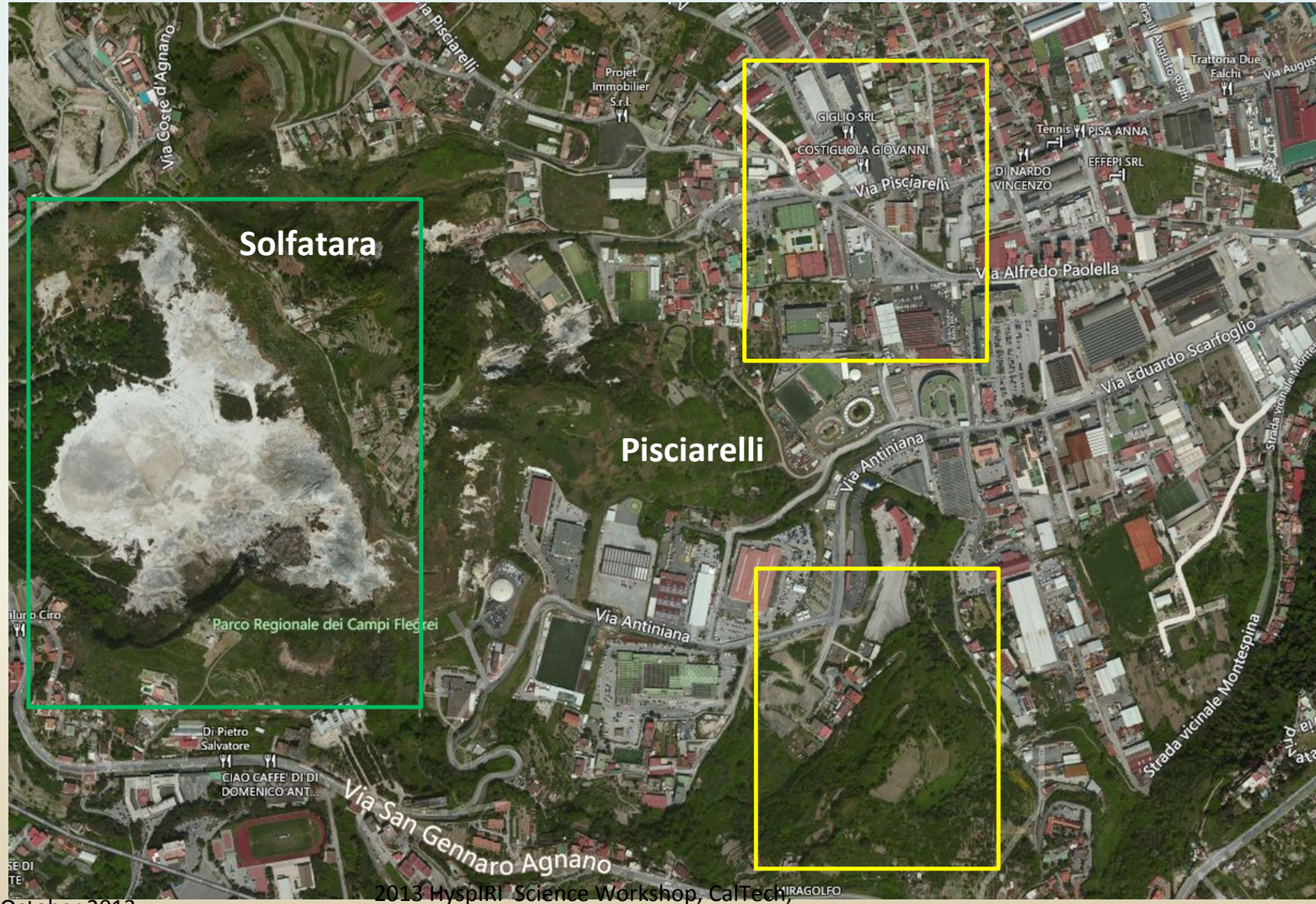
CAMPI FLEGREI AREA

Campi flegrei experienced a rapid uplift from 2006 which
In 2012-2013 has increased of surveilance requests from Italian Civil Protection including systematic observation from space by SAR and Thermal Infrared sensors





Velocity map from COSMO Skymed Series ascending orbit
1 cycle correspond to 1 cm/year.

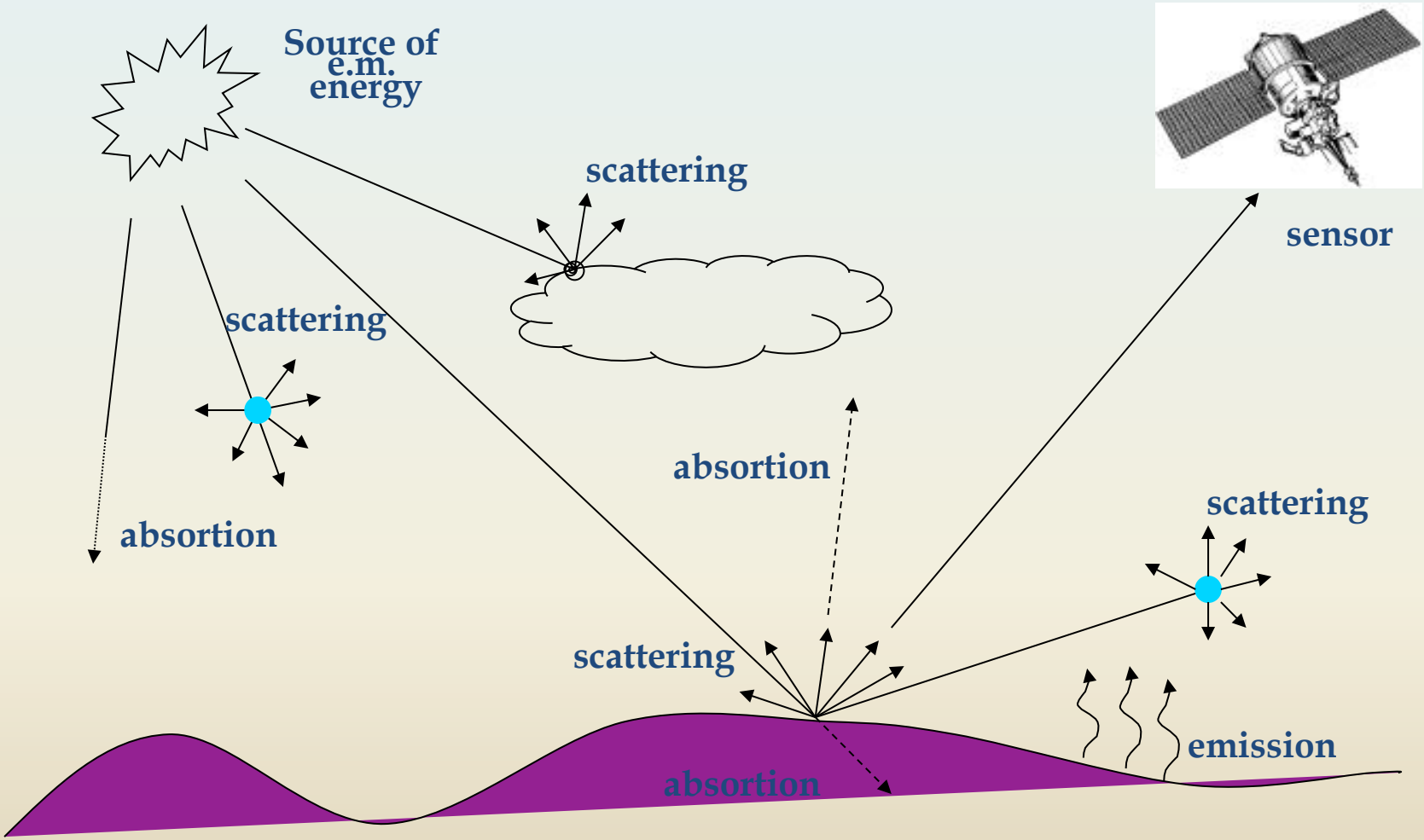

Solfatara
Pisciarelli
Parco Regionale dei Campi Flegrei
Via Coste d'Agnano
Via Pisciarelli
Via Alfredo Paolella
Via Eduardo Scarfoglio
Via Antiniana
Via San Gennaro Agnano
Strada vicinale Montespina
Projet Immobilier S.r.l.
GIGLIO SRL
COSTIGLIOLA GIOVANNI
DI NARDO VINCENZO
Tennis
PISA ANNA
EFFEPI SRL
Trattoria Due Falchi
Di Pietro Salvatore
CIAO CAFFE' DI DI DOMENICO ANT...

Processing steps:

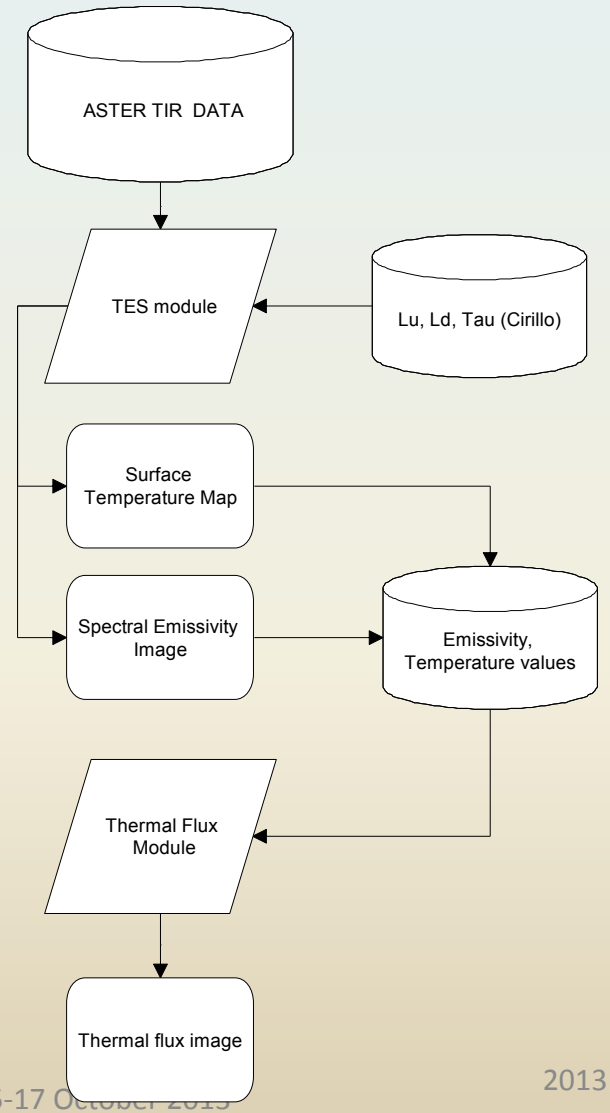
- Atmospheric profiles are used in order to remove the atmosphere contribution. Concerning the Solfatara area the Pratica di Mare profiles have been considered (free download from: http://weather.uwyo.edu/upperair/sounding.html)
- Temperature and Emissivity Separation (TES) algorithm is applied in order to obtain the surface temperature map.
- Field campaigns to validate

Sensor	N. Data
AVHRR	36 (from 15 December 012)
MODIS	31(from 15 December 2012)
ASTER	27 (relativi alla serie storica 2002-2013)
MSG	Continui ogni 5 minuti

Energy interaction e.m. - Atmosphere - Surface



Radiances of TIR ASTER data are atmospherically corrected by removing the atmosphere contribution



Satellite and air borne multispectral thermal infrared instruments collect an at sensor radiance

$$L=[\varepsilon_s \cdot B(T_s)+(1-\varepsilon_s)\cdot L_d]\cdot\tau+L_u$$

that is a function of surface temperature and spectral emissivity, where L_d and L_u are the downwelling and upwelling radiances, τ the atmospheric transmittance and B is the Planck function.

A N-channel instruments gives N radiance measurements in the N+1 unknowns (temperature and spectral emissivity). The evaluation of temperature and emissivity is therefore an undetermined problem with infinite solutions, and is generally known in the remote sensing community as the Temperature Emissivity Separation problem (TES).

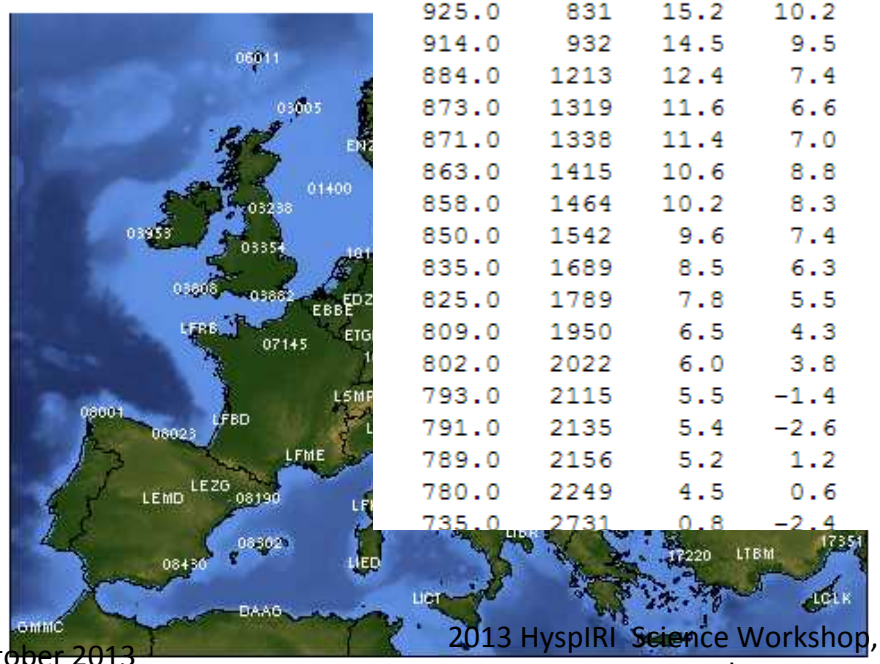
Atmospherical profile

University of
College of Engi
Department of Atmospheri

Region Type of

Europe Text: List

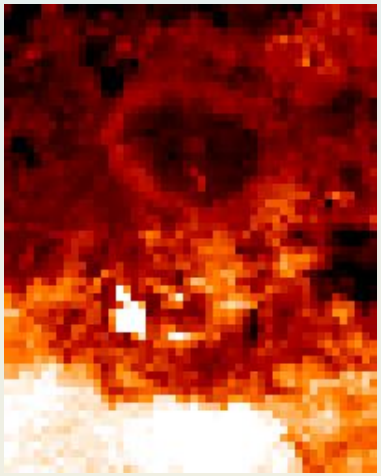
Click on the image to request a so



16245 LIRE Pratica Di Mare Observations at 00Z 08 Oct 201

PRES hPa	HGHT m	TEMP C	DWPT C	RELH %	MIXR g/kg	DRCT deg	SKNT knot	THTA K	THTE K	THTV K
1015.0	32	17.8	15.2	85	10.81	0	0	289.7	320.3	291.6
1007.0	102	19.8	13.8	68	9.94	72	3	292.4	320.9	294.1
1000.0	163	19.4	12.4	64	9.12	135	6	292.6	318.8	294.2
967.0	452	18.6	9.6	56	7.81	140	10	294.6	317.4	295.9
966.0	461	18.5	9.6	56	7.83	140	10	294.6	317.4	296.0
935.0	739	16.0	10.1	68	8.34	155	10	294.8	319.1	296.3
925.0	831	15.2	10.2	72	8.51	180	11	294.9	319.6	296.4
914.0	932	14.5	9.5	72	8.19	150	10	295.1	319.0	296.6
884.0	1213	12.4	7.4	72	7.35	165	12	295.8	317.4	297.1
873.0	1319	11.6	6.6	71	7.05	140	10	296.0	316.8	297.3
871.0	1338	11.4	7.0	75	7.28	135	10	296.0	317.4	297.3
863.0	1415	10.6	8.8	89	8.30	150	12	295.9	320.2	297.4
858.0	1464	10.2	8.3	88	8.05	160	14	296.0	319.6	297.5
850.0	1542	9.6	7.4	86	7.65	155	15	296.2	318.7	297.6
835.0	1689	8.5	6.3	86	7.22	170	14	296.5	317.8	297.8
825.0	1789	7.8	5.5	86	6.93	140	11	296.8	317.3	298.0
809.0	1950	6.5	4.3	86	6.49	150	15	297.1	316.4	298.3
802.0	2022	6.0	3.8	86	6.30	141	14	297.3	316.1	298.4
793.0	2115	5.5	-1.4	61	4.36	130	13	297.8	311.0	298.5
791.0	2135	5.4	-2.6	56	4.01	133	14	297.9	310.1	298.6
789.0	2156	5.2	1.2	75	5.32	136	15	297.9	313.8	298.8
780.0	2249	4.5	0.6	76	5.16	150	19	298.1	313.6	299.0
735.0	2731	0.8	-2.4	79	4.38	144	19	299.1	312.5	299.9

Solfatara (Naples): 2002-2006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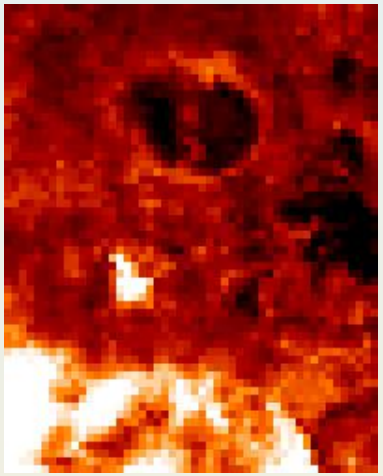
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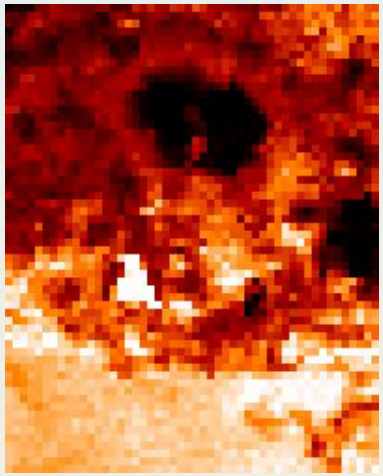
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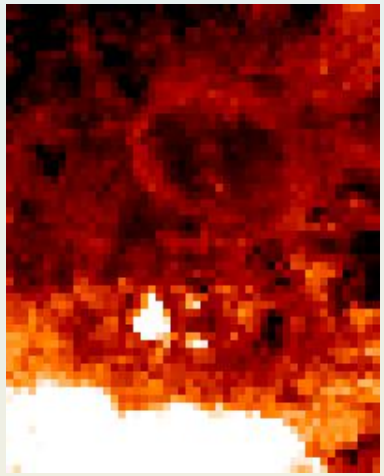
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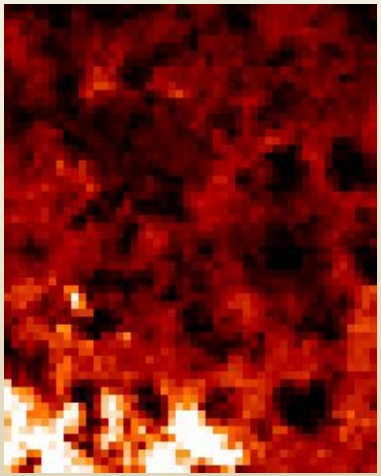
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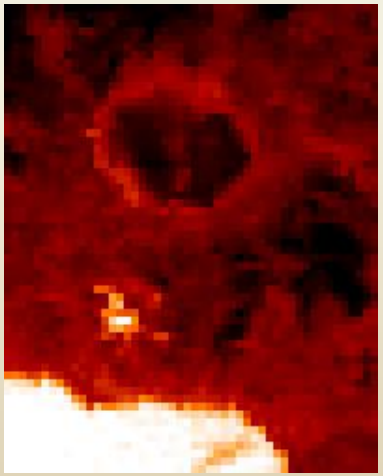
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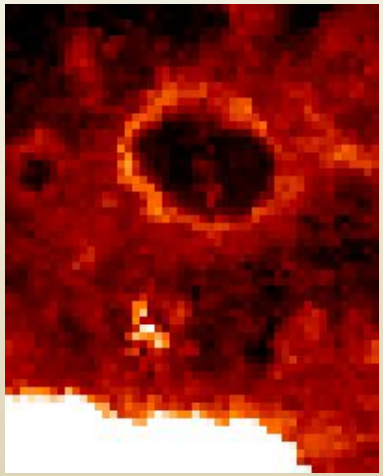
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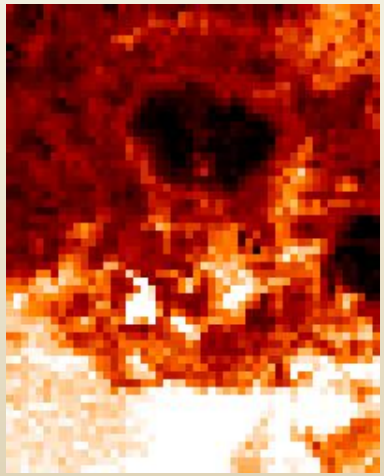
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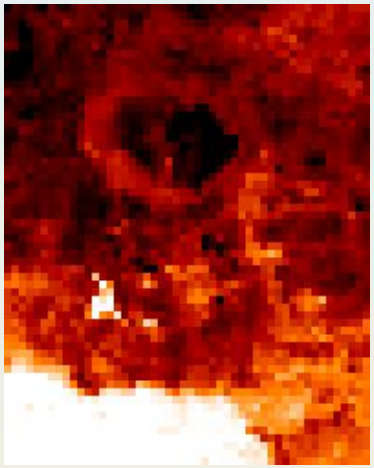
Solfatara (Naples): 2007-2011



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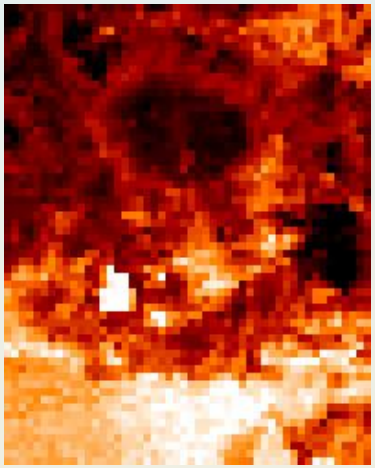

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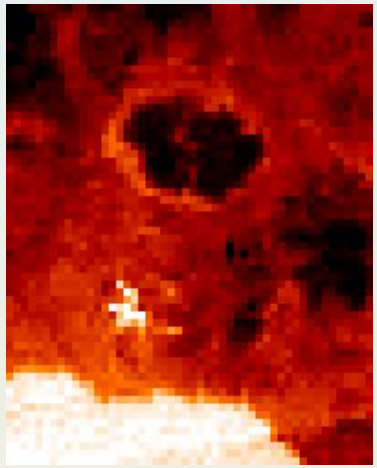

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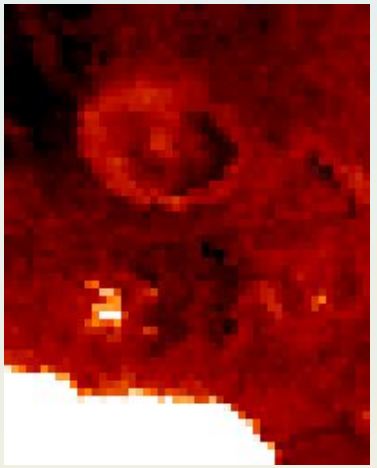

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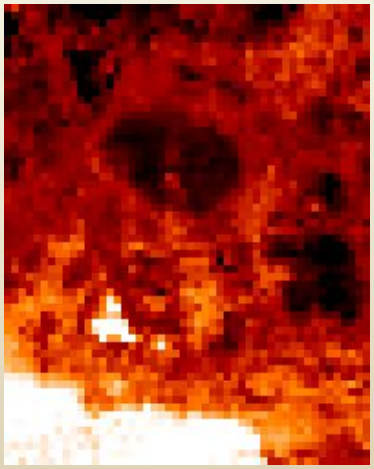

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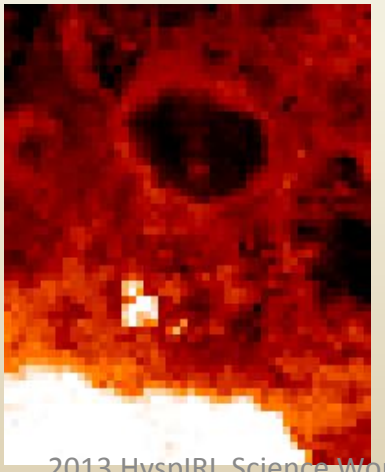

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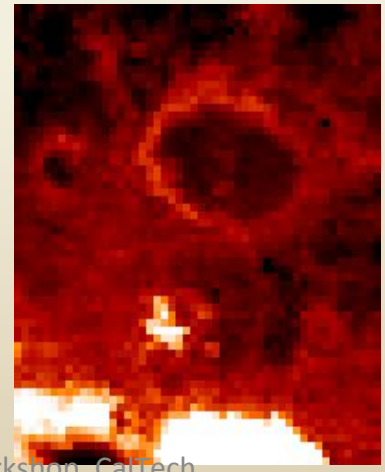

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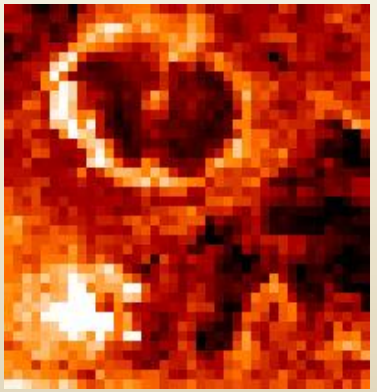

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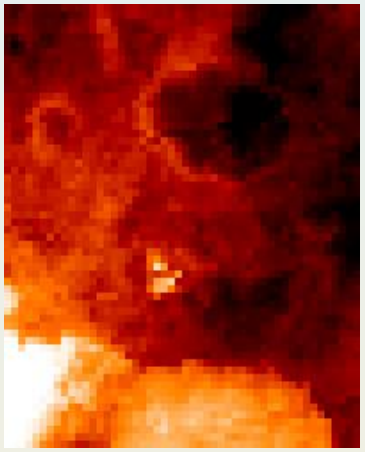

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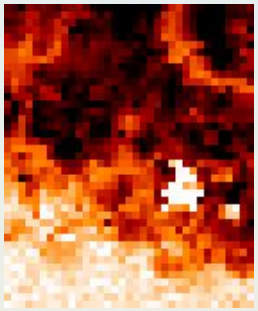

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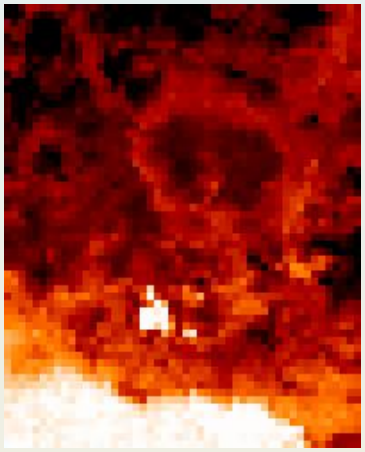

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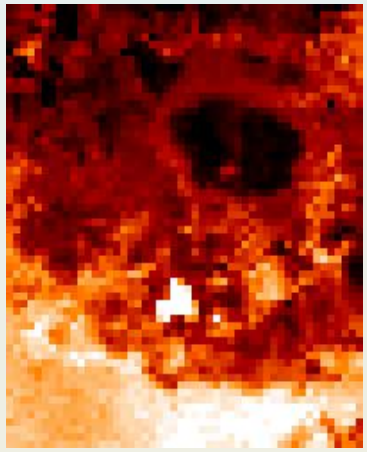

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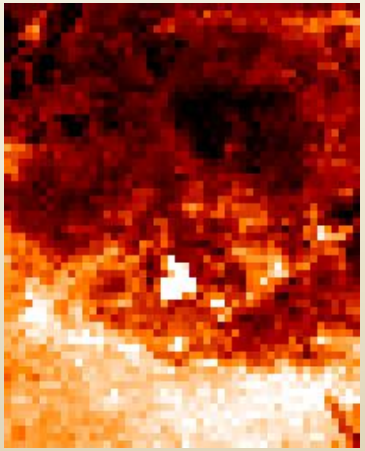

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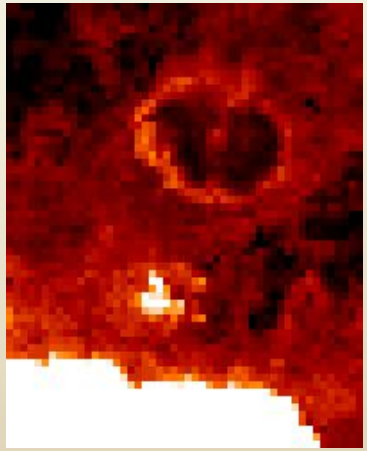

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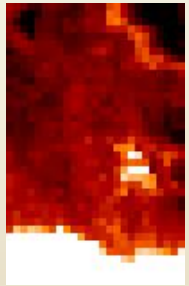

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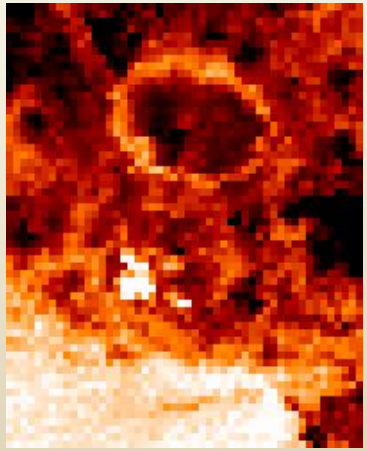
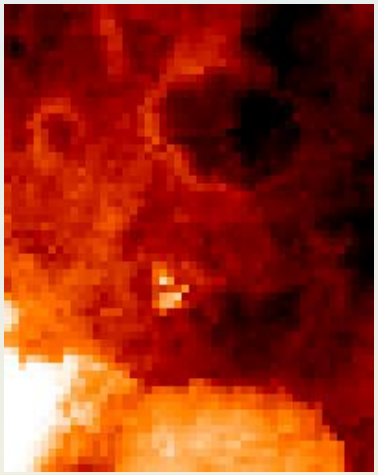


25/02/2012

Solfatara (Naples): 2011-2012



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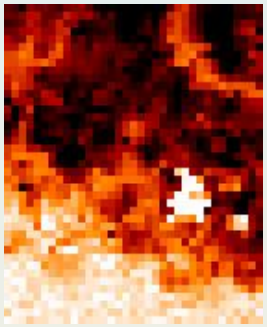

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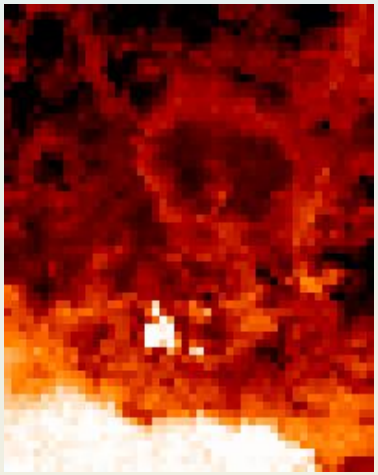

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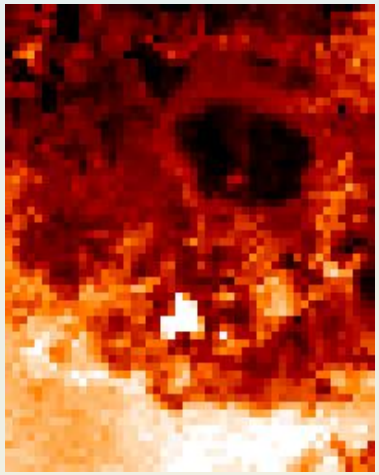

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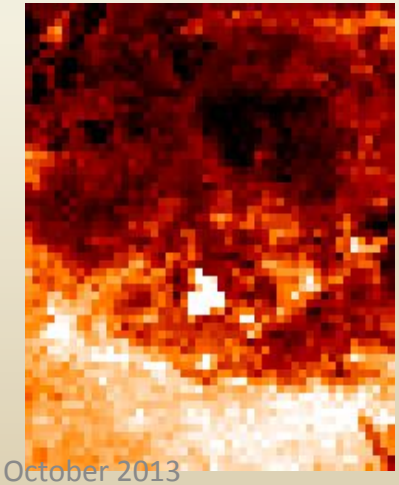

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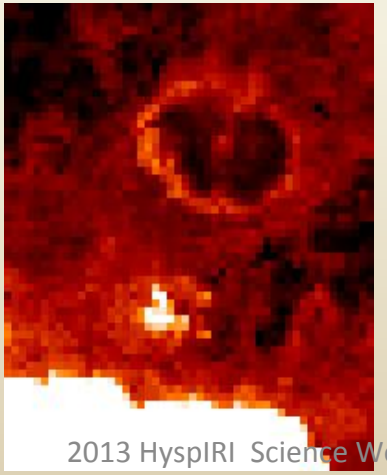

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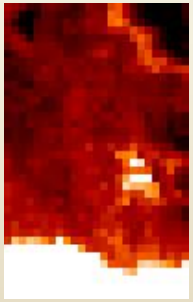

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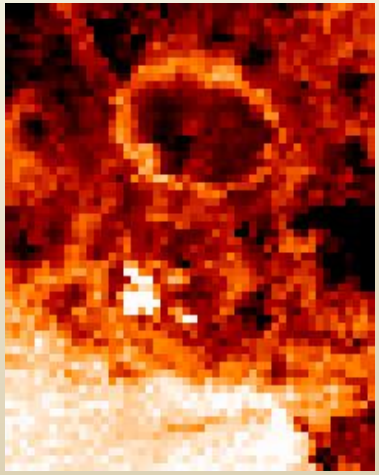

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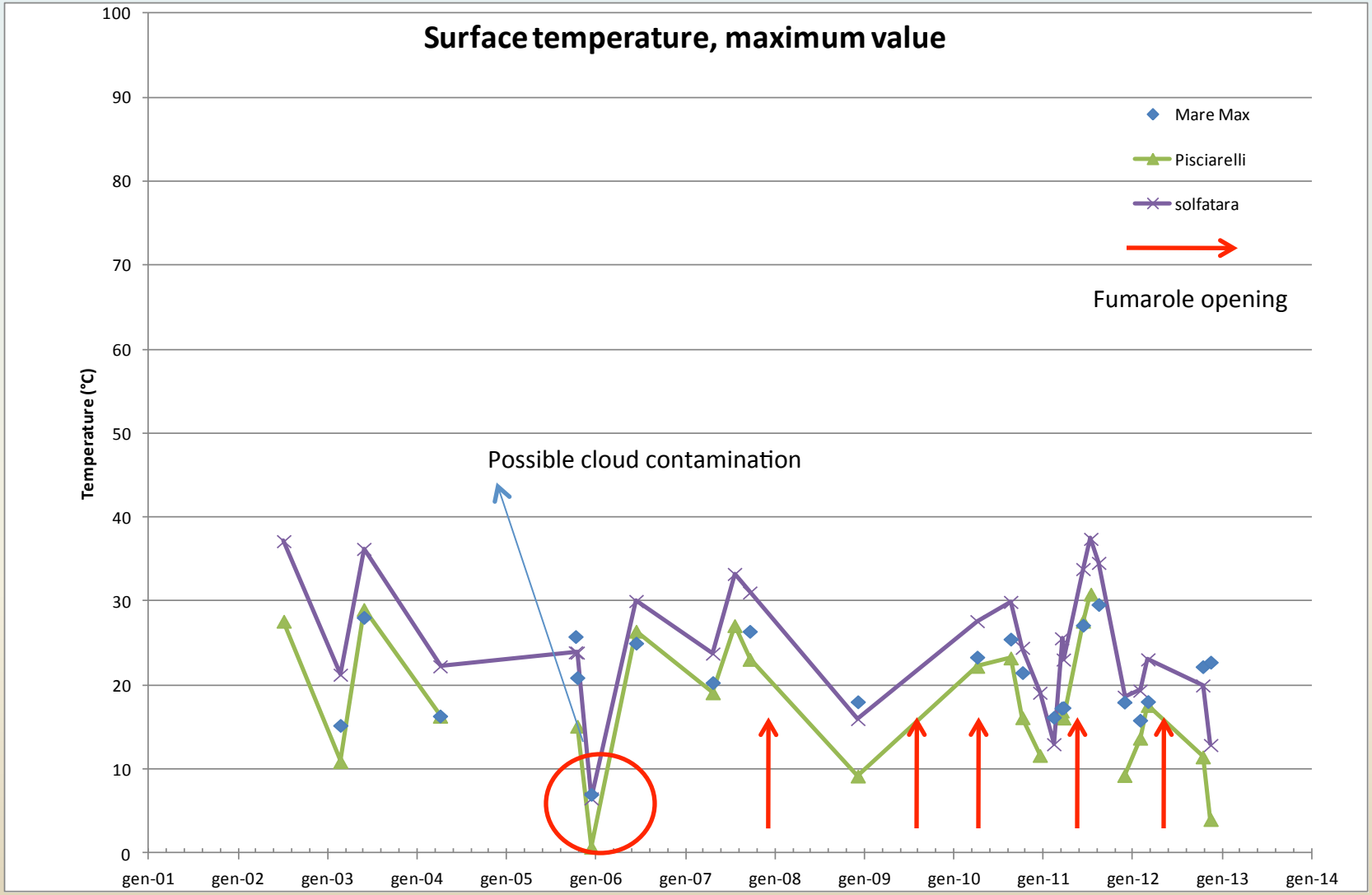
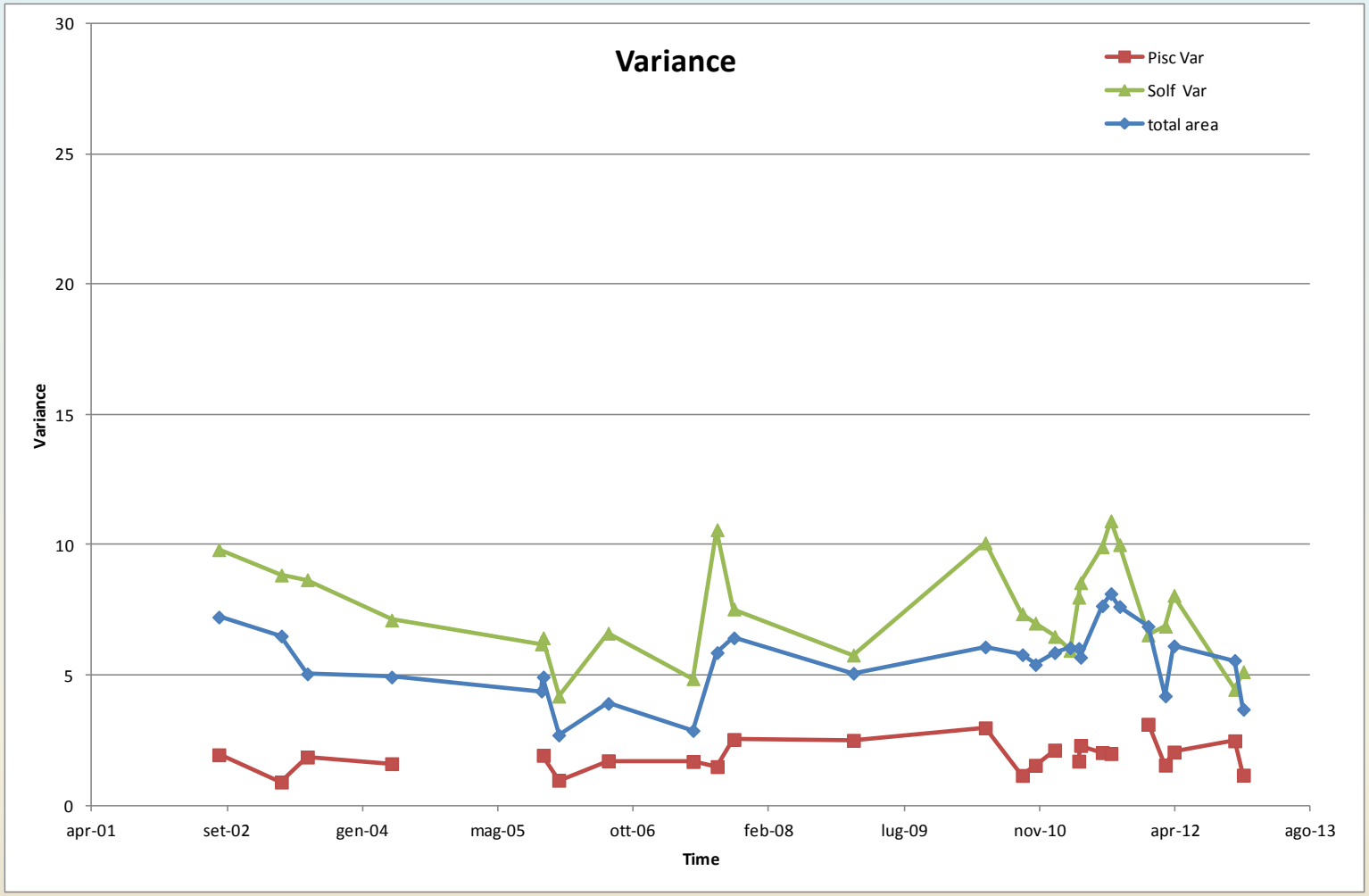
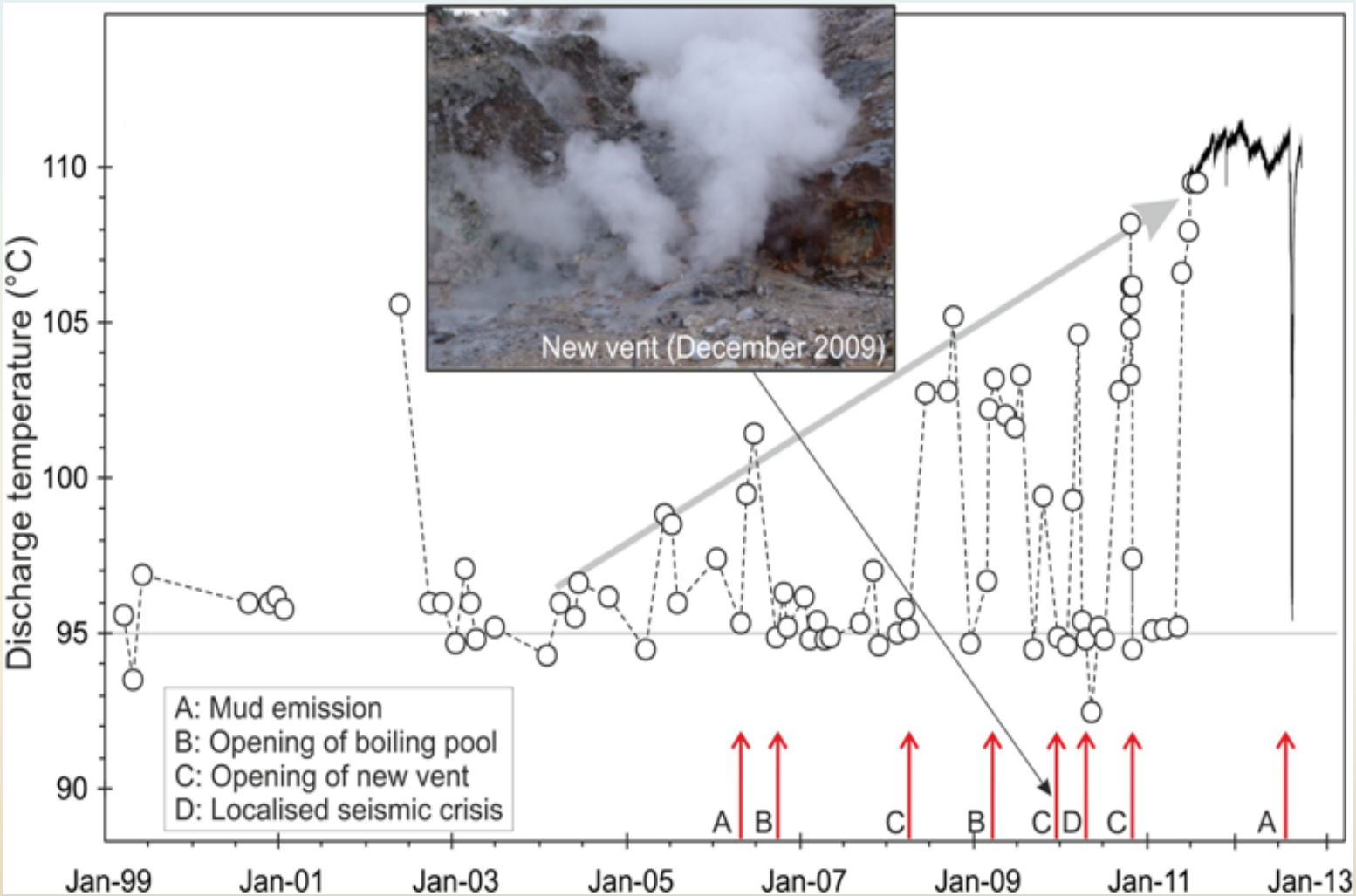
Solfatara (Naples): 2011-2012

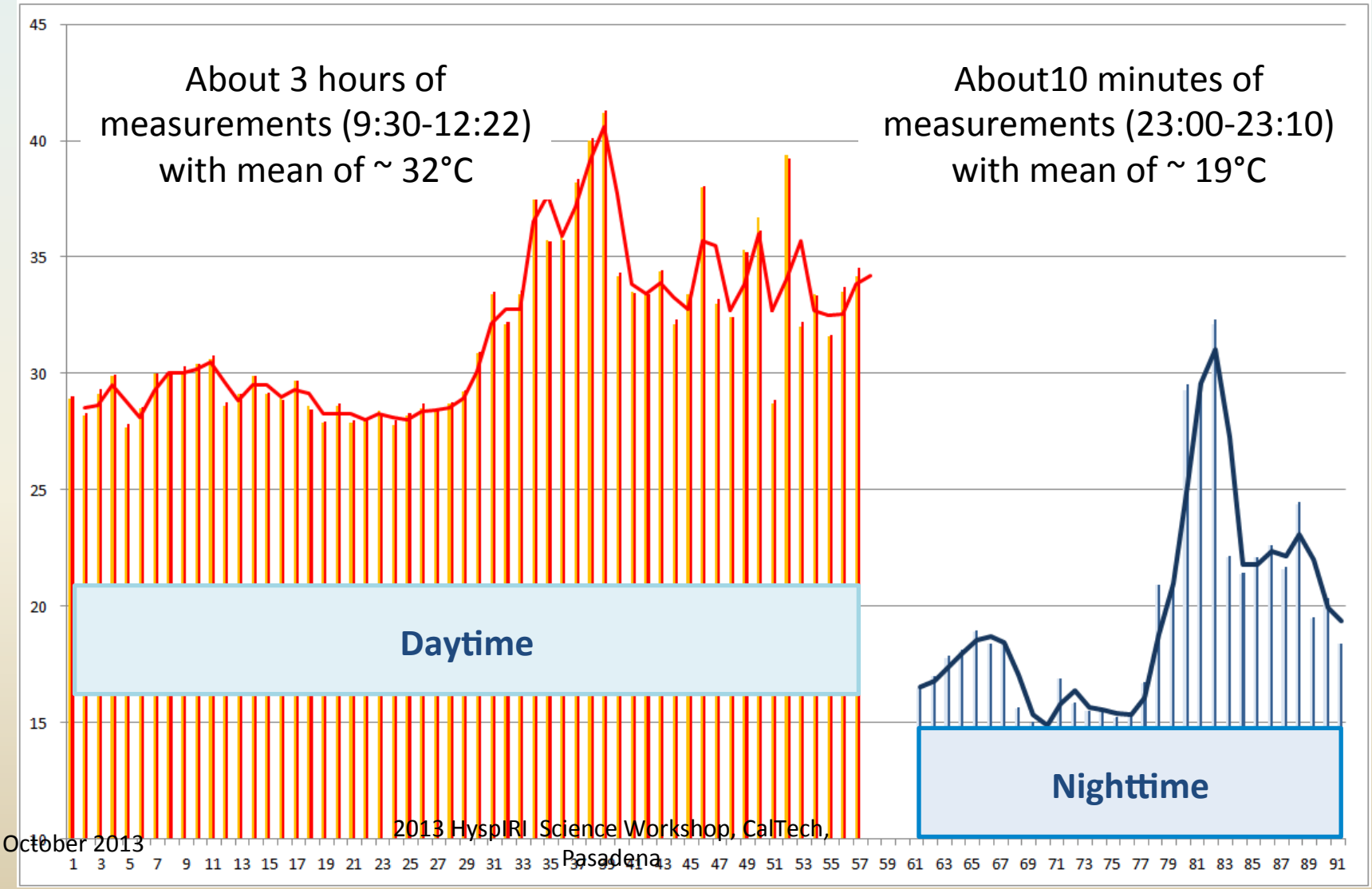




Variance has been calculate to enlighten small variations in temperature


New vent (December 2009)
Discharge temperature (°C)
110
105
100
95
90
A: Mud emission
B: Opening of boiling pool
C: Opening of new vent
D: Localised seismic crisis
A B C B C D C A
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09
Jan-11
Jan-13

Field campaigns: Validation



CONCLUSIONS 1/2

To monitoring of active volcanoes the systematic acqusition of high resolution thermal data and the subsequent analyis of time series may improve the capability to detect small surface temperature variation related to changes in volcanic activity level and contribute to the early warnig systems

- Both spatial resolution and rivisit time for swir- tir satellite systems is a key parameter especially for areas located near urban settlements

- Day and night acquisitions of tir data are required to detect changes in the avarge thermal cycle . night time data are very important to reveal low intensity thermal anomalies on land and in water

CONCLUSION 2/2

- Creation of data archives aviable to develop suitable techniques for thermal analysis of volcanic phenomena is a very important issue

- The comparison of surface temperature retrievals at different scale is an important issue which support the request from scientific and operational community to have both low and high spatial resolution system in space

- HyspIRI is the most mature system design to accomplish these requests