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7th Sentinel-3 Validation Team Meeting 2022

18-20 October 2022 | ESA-ESRIN | Frascati (Rm), Italy

Sentinel 3 SLSTR images for infrared remote sensing of volcanic activity

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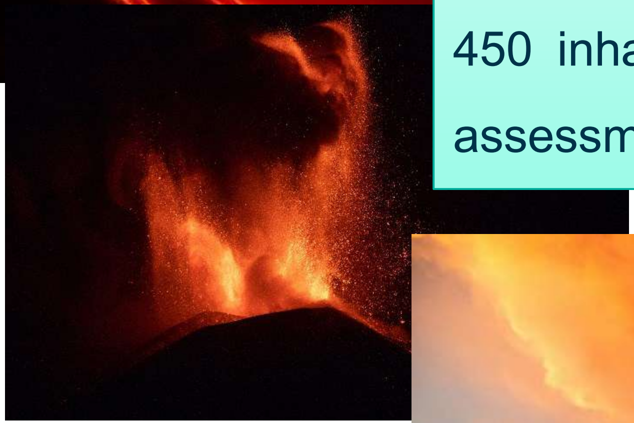
MOTIVATIONS

Volcanic eruptions pose a significant threat to human civilization, being among the most hazardous natural phenomena. Mt. Etna as well as Stromboli volcano are among the most active volcano worldwide, characterized by persistent activity at summit, alternated by flank eruptions. The population living in the area around Mt. Etna has almost tripled during the last 150 years, increasing the volcanic risk, at the same time Stromboli island goes from 450 inhabitants to thousands of tourists during the summer. A correct volcanic hazard assessment is an essential component in reducing the losses due to volcanic disasters.



The synoptic view captured by multi-source satellite imagery over volcanoes can benefit hazard monitoring efforts, both following the different phases and intensities of an eruption, as well as helping in nowcasting and eventually forecasting the areas potentially threatened by hazardous phenomena.

Satellites and sensors for Volcano Monitoring

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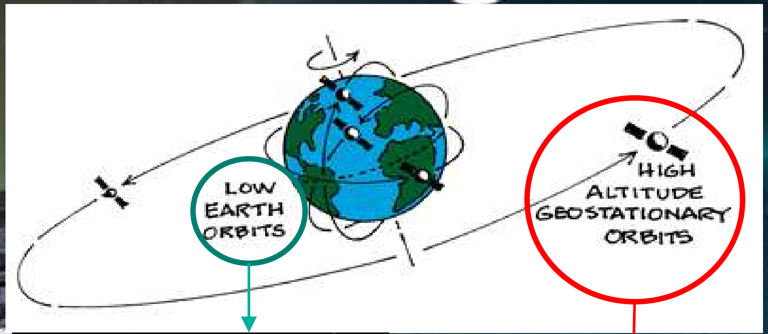
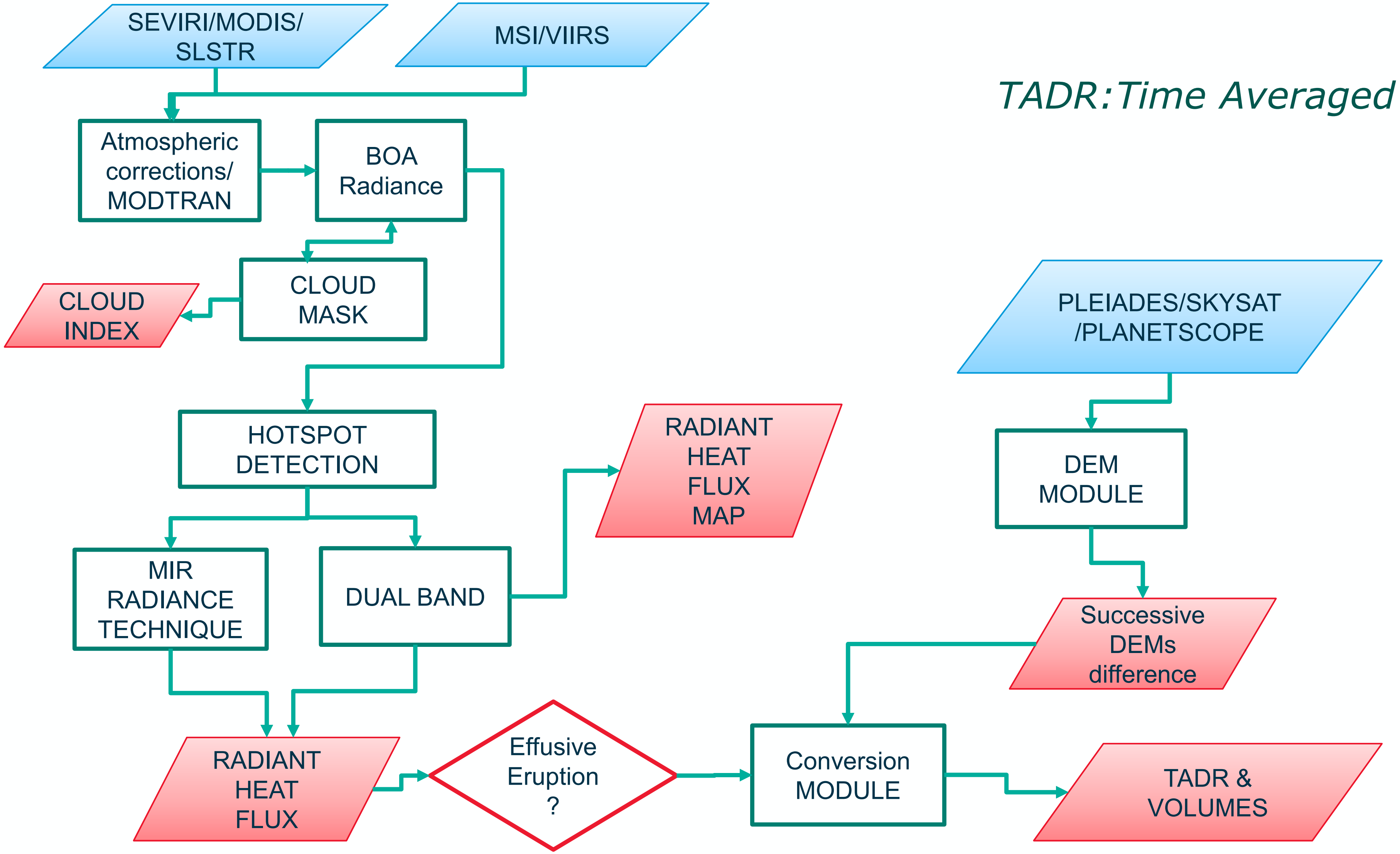
Satellite Sensor	Spatial Resolution	Revisit Time	Derived Product
MSG-SEVIRI	3 km	15 minutes	Radiant Heat Flux, TADR
EOS-MODIS	1 km	12 h	Radiant Heat Flux, TADR
Sentinel 3-SLSTR	1 km	12 h	Radiant Heat Flux, TADR
NPP/JPSS-VIIRS	375 - 750 m	12 h	Radiant Heat Flux, TADR
Landsat 8- OLI	15 - 30 m	7-14 days	Lava flow thermal map
Sentinel 2- MSI	10 - 60 m	2-3 days	Lava flow thermal map
EOS-ASTER	15 - 90 m	On demand	DEM, Lava flow area/thickness
Pleiades-1A, -1B	0.5 - 2 m	On demand	DEM, Lava flow area/thickness
Doves-PlanetScope	3.7 m	~1 day	DEM, Lava flow area/thickness
SkySat	0.7 - 1 m	On demand	DEM, Lava flow area/thickness



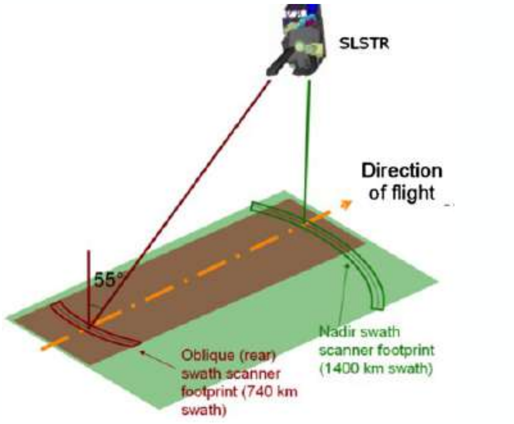
SPACE-BASED VOLCANO MONITORING SYSTEM

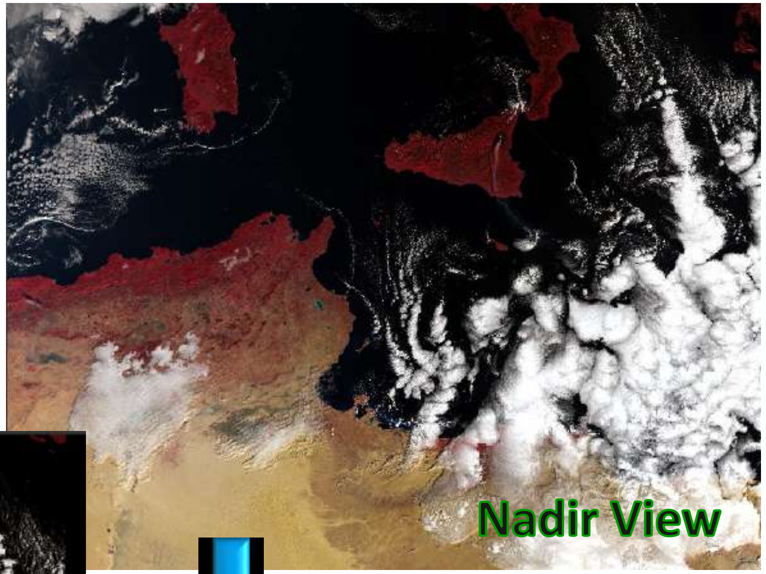
TADR:Time Averaged Discharge rate



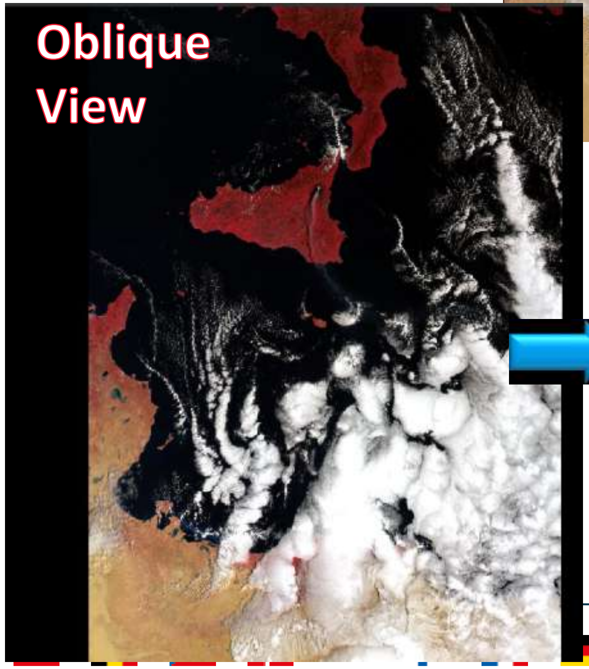
Sentinel-3 SLSTR

SLSTR provides dual-viewing angle, highly accurate imaging radiometry in multiple channels spanning the visible to longwave infrared spectral regions

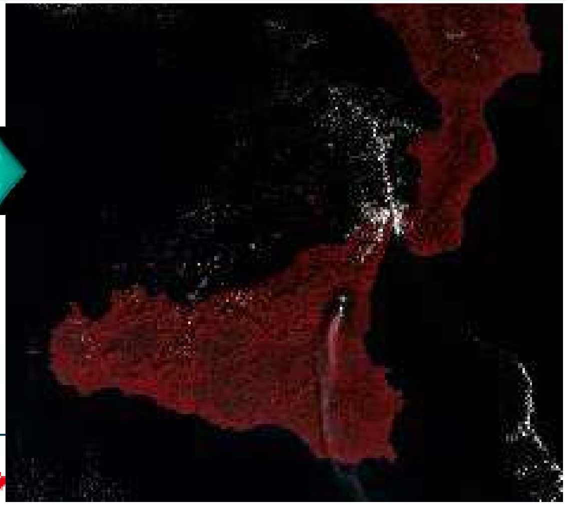




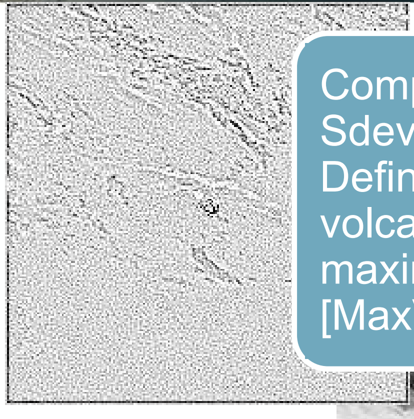
Band	Wavelenght	Saturation Temperature	Radiometric Accuracy
S7	3.7 µm	311 K	< 0.2 K (NEΔT < 50 mK)
F1	3.7 µm	~500 K	< 3 K (NEΔT < 1 K)
S8	10.85 µm	311 K	< 0.2 K (NEΔT < 50 mK)
F2	10.85 µm	~400 K	< 3 K (NEΔT < 0.5 K)

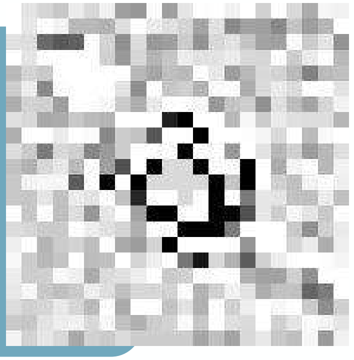


Radiometric Calibration → Atmospheric Correction → Dual-Angle Algorithm

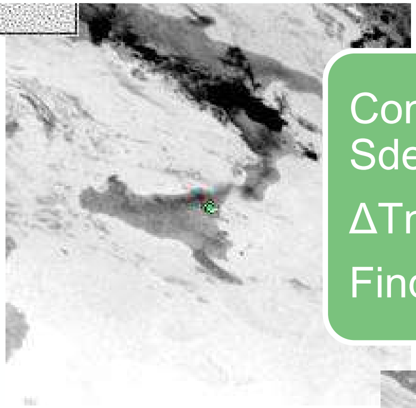


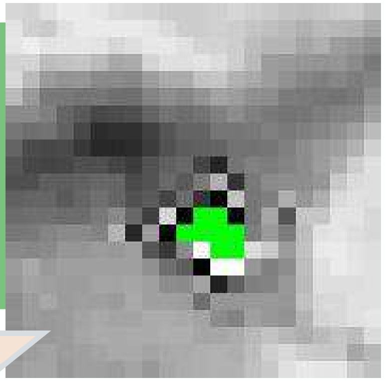
HOTSPOT DETECTION ALGORITHM





Compute Spatial Standard Deviation $Sdev(\Delta T)$ for $\Delta T = T_{3.9\mu m} - T_{10.8\mu m}$ image. Define a volcanic area (VA) and a non volcanic area (NVA). Compute moreover the maximum variation of $T_{3.9\mu m}$ in NVA [$MaxVar(T_{3.9\mu m})$].

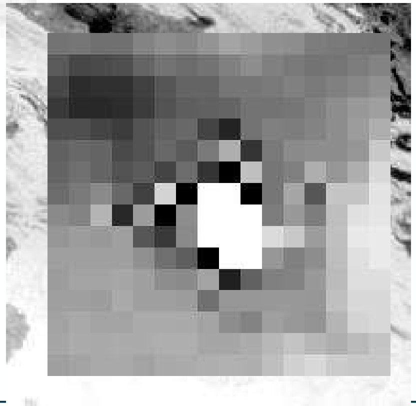


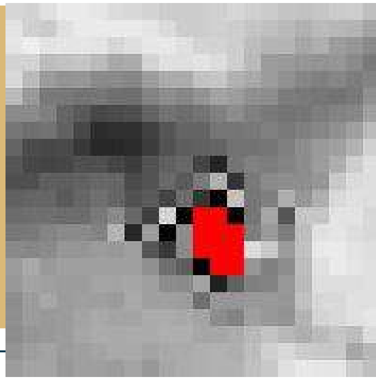


Compute $\Delta Tnat$ as the maximum value of $Sdev(\Delta T)$ in NVA.

$\Delta Tnat = \max[Sdev(\Delta T)]_{NVA}$

Find the pixel in VA where $Sdev(\Delta T) > \Delta Tnat$





Scan for all the green pixels' neighbors and classify them as hotspot if:

$$T_{3.9\mu m} - \min(T_{3.9\mu m}) > MaxVar(T_{3.9\mu m})$$

or

$$T_{3.9\mu m} > \mathrm{mean}(T_{3.9\mu m})_{NVA} T + n*\mathrm{std}(T_{3.9\mu m})_{NVA}$$

Ganci et al., 2011
doi:10.4401/ag-5338

RADIANT HEAT FLUX

FINAL PRODUCTS

- **RADIATIVE POWER**
- **CLOUD INDEX**

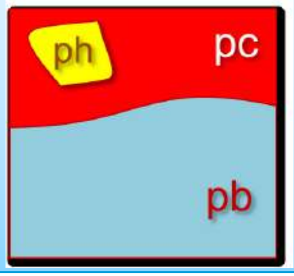
NCSE Lava Fountain

$$Q = \frac{A_{sampl}\,\varepsilon\sigma}{a\,\varepsilon_{MIR}} L_{MIR,h}$$

MIR Radiance Method

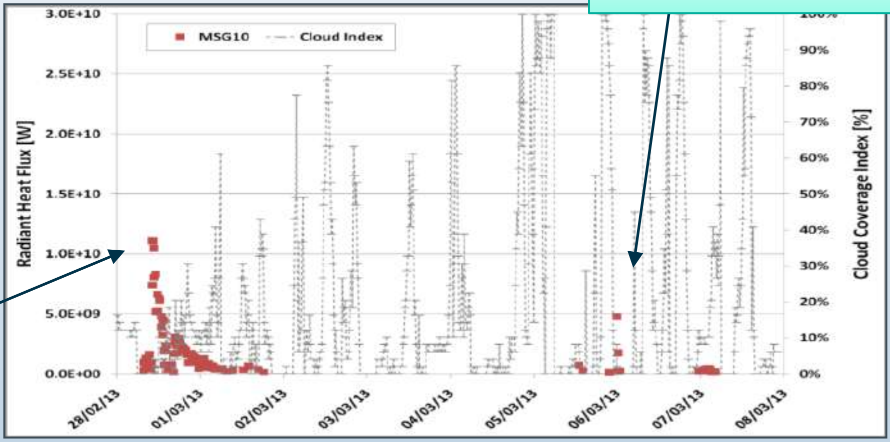
Wooster et al., 2003

$$\begin{cases} RC_{SWIR} = p_b L_{SWIR}(T_b) + p_c L_{SWIR}(T_c) + p_h L_{SWIR}(T_h) \\ RC_{MIR} = p_b L_{MIR}(T_b) + p_c L_{MIR}(T_c) + p_h L_{MIR}(T_h) \\ RC_{TIR} = p_b L_{TIR}(T_b) + p_c L_{TIR}(T_c) + p_h L_{TIR}(T_h) \end{cases}$$



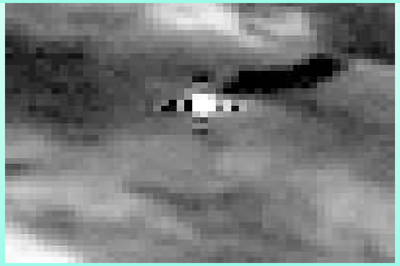
CLOUD INDEX

NCSE Lava Fountain

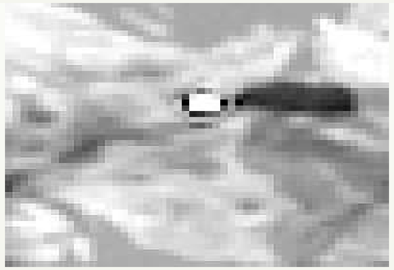


$$i_{cloud} = \frac{N_{VAcloudy}}{N_{VA}}$$

05/03/13 23:45 GMT

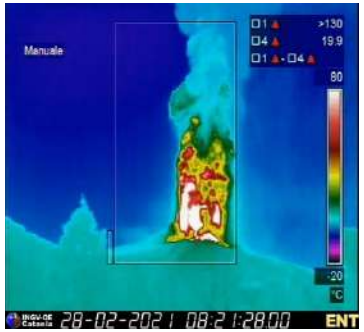


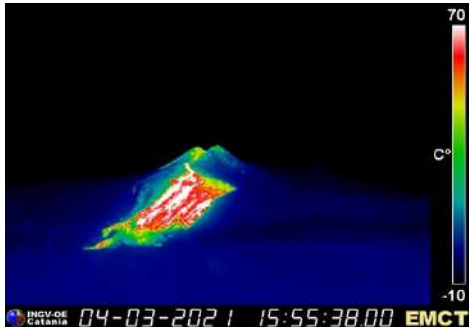
28/02/13 10:45 GMT



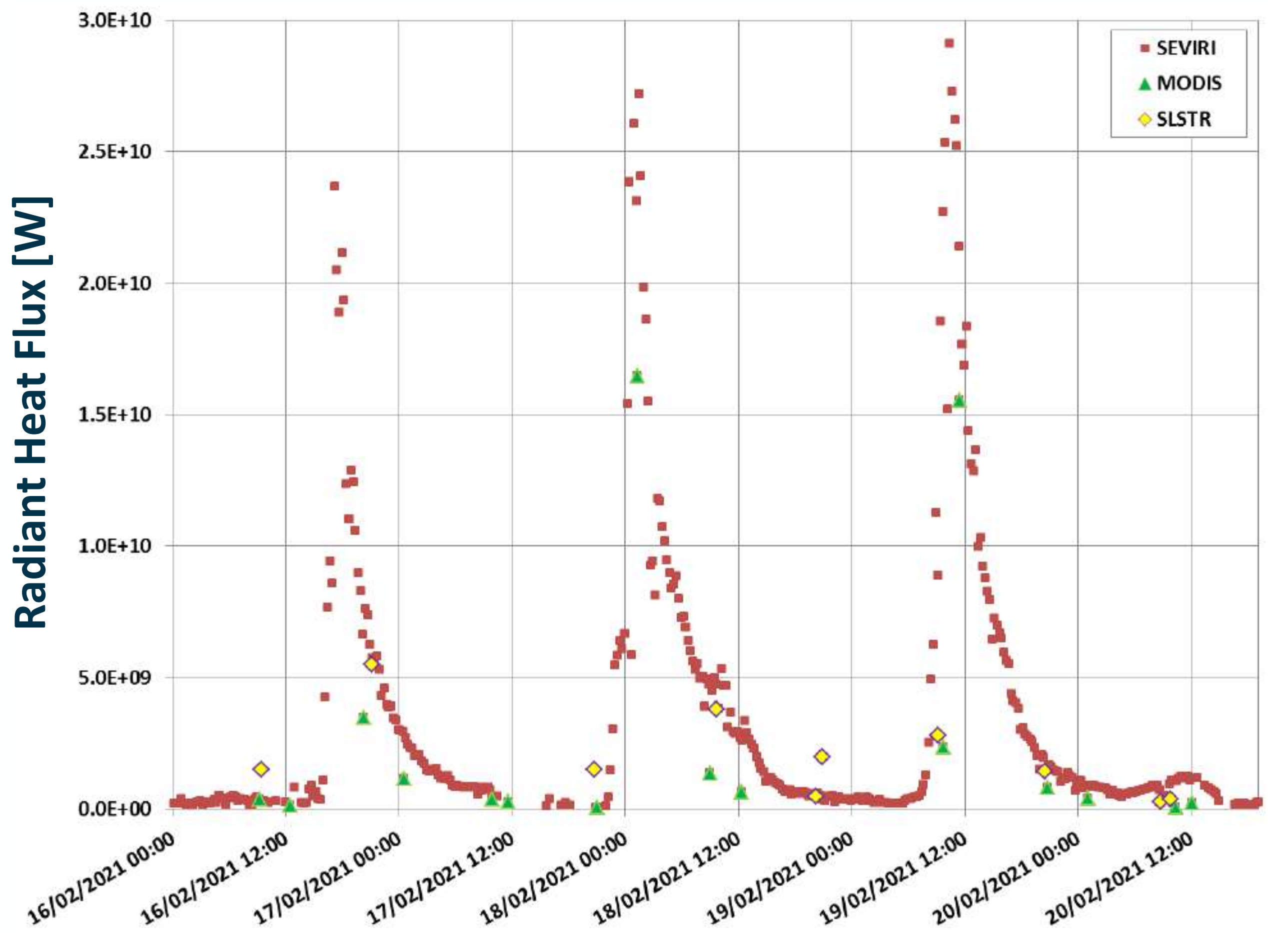
Case study: Etna 2021 eruptive activity

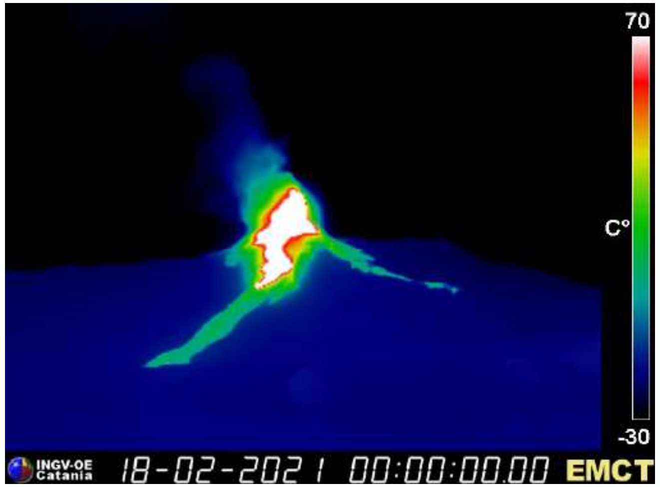
Since 16 February, 2021 Etna experienced about 60 paroxysmal episodes at the South East Crater (SEC) with lava fountains over 1000 m high, small pyroclastic flows, fast lava flows, substained eruptive columns often reaching more than 10 km elevation above sea level.

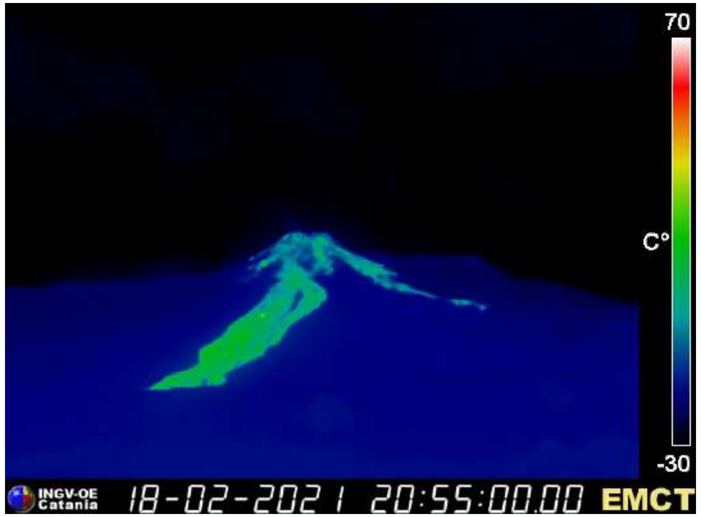




Case study: Etna 2021 eruptive activity





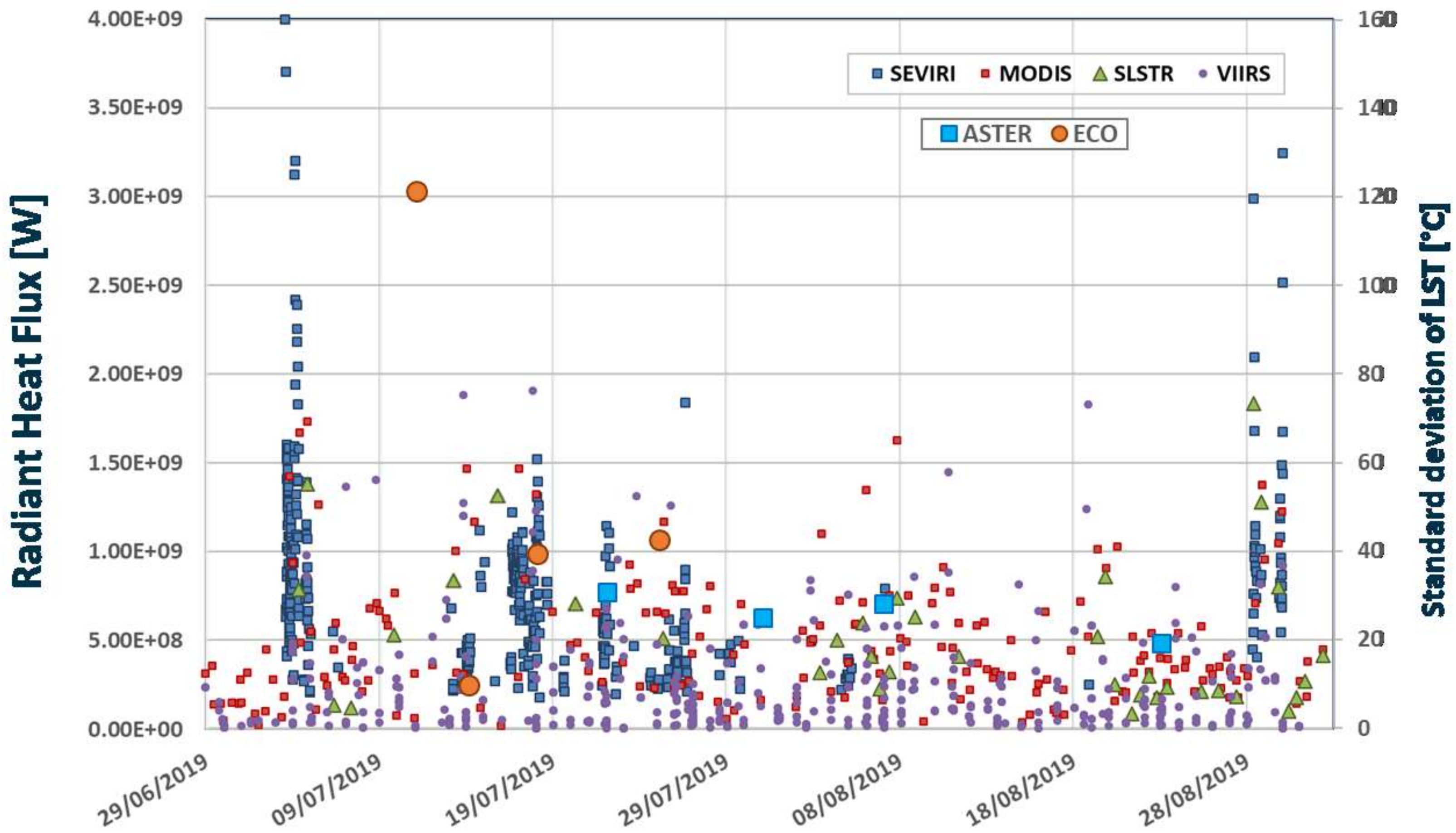


Case study: Stromboli 2019 eruption

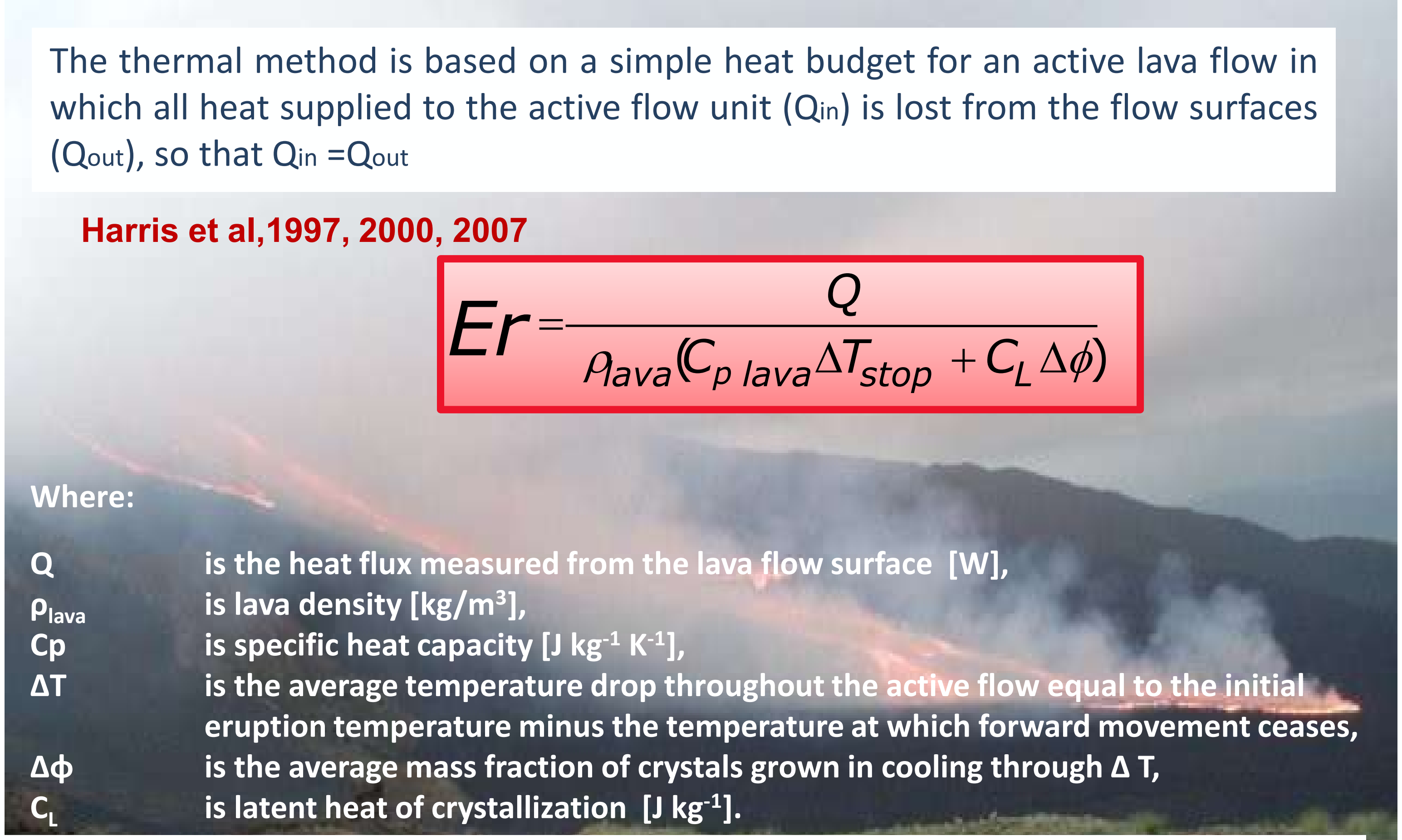
In 2019, Stromboli volcano experienced one of the most violent eruptive crises in the last hundred years. Two paroxysmal explosions interrupted the 'normal' mild explosive activity during the tourist season.

The activity started on 3 July 2019 with a strong paroxysmal explosion (Mattia et al.,2021). The explosion generated an eruptive plume around 6–8.4 km in height (Andronico et al., 2021) and two PDCs that flowed down the Sciara del Fuoco and generated a small tsunami. After the July explosion, lava began outpouring from the SWC, and sporadically from the NEC, and this effusive activity, continued until 30 August 2019. On 28 August 2019, a second paroxysmal explosion occurred, again forming a PDC that moved down the Sciara del Fuoco, generating another small tsunami.

Case study: Stromboli 2019 eruption



Satellite-derived estimates of effusion rate



The thermal method is based on a simple heat budget for an active lava flow in which all heat supplied to the active flow unit (Q_{in}) is lost from the flow surfaces (Q_{out}), so that $Q_{in} = Q_{out}$

Harris et al,1997, 2000, 2007

$$Er = \frac{Q}{\rho_{lava}(C_{p\,lava}\Delta T_{stop} + C_L \Delta\phi)}$$

Where:

Q	**is the heat flux measured from the lava flow surface [W],**
ρ_{lava}	**is lava density [kg/m^3],**
Cp	**is specific heat capacity [J kg^{-1} K^{-1}],**
ΔT	**is the average temperature drop throughout the active flow equal to the initial eruption temperature minus the temperature at which forward movement ceases,**
Δϕ	**is the average mass fraction of crystals grown in cooling through Δ T,**
C_L	**is latent heat of crystallization [J kg^{-1}].**

Vescicularity	ρ_{lava}	Cp	C_L	ΔT	Δφ
10-34%	2600	1150	3.50E+05	100-200	0.3-0.54

Time Averaged Discharge Rate (TADR)

Harris et al., 2010

$Er = x\ A$ ⟷ $Er = k_{TADR}\ Q$

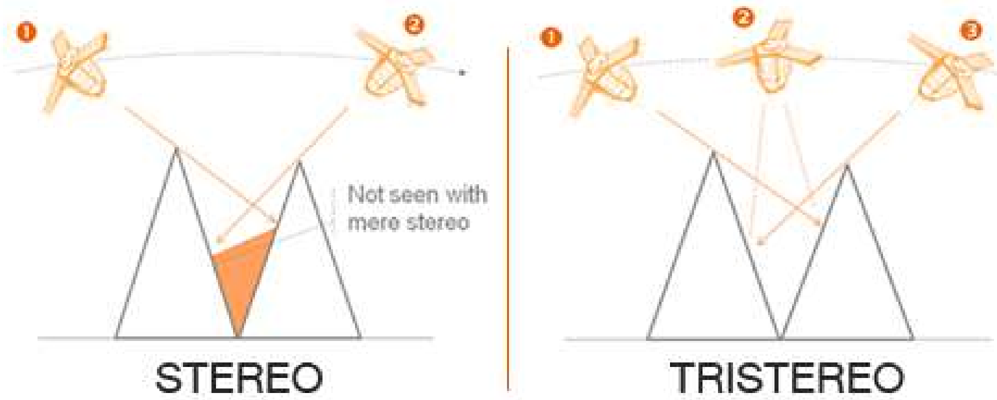
This relationship was also supported by laboratory experiments (Garel et al., 2012) proving how the heat radiated by the flow surface is proportional to the magma discharge rate after a transient time, when a steady value is reached.

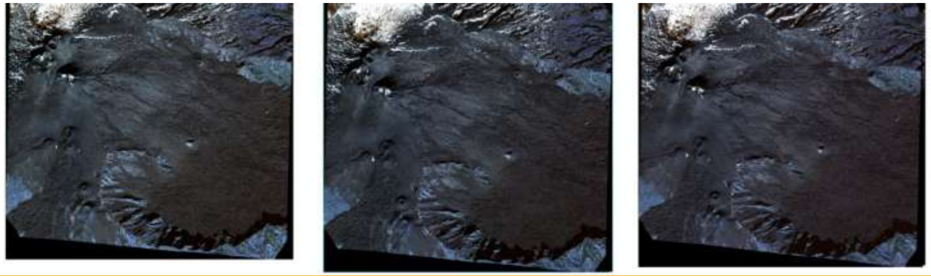
k_{TADR} ???

It depends on many parameters: rheology, silica content, topography, cooling, flow insulation,….

Digital elevation model from tri-stereo Pleiades (Neo) satellite imagery

0.5 m spatial resolution DEM of Etna volcano





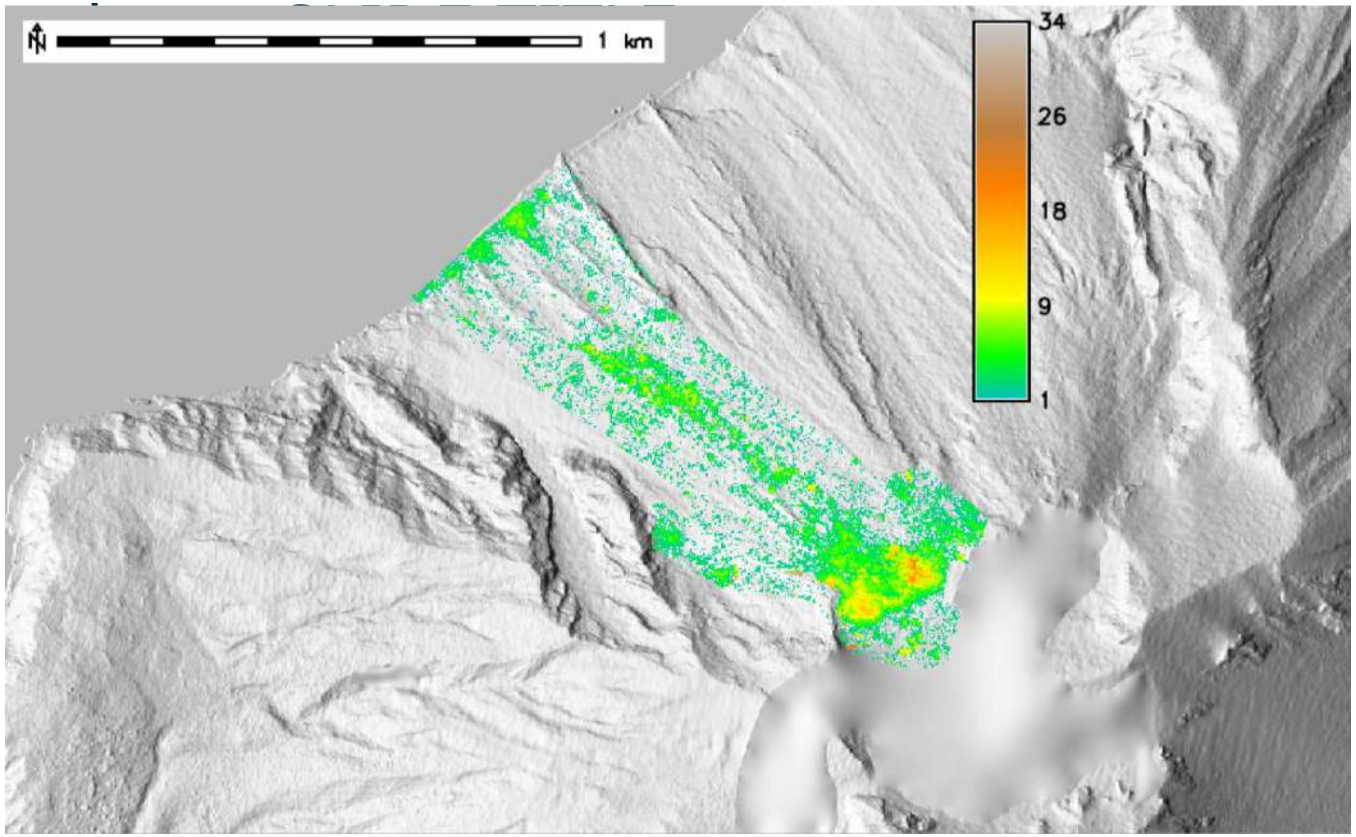
The 3D processing of the tri-stereo Pléiades imagery is performed using the free and open source MicMac (Multi-images Correspondances, Méthodes Automatiques de Corrélation) photogrammetric library developed by the French IGN (Institut Géographique National).

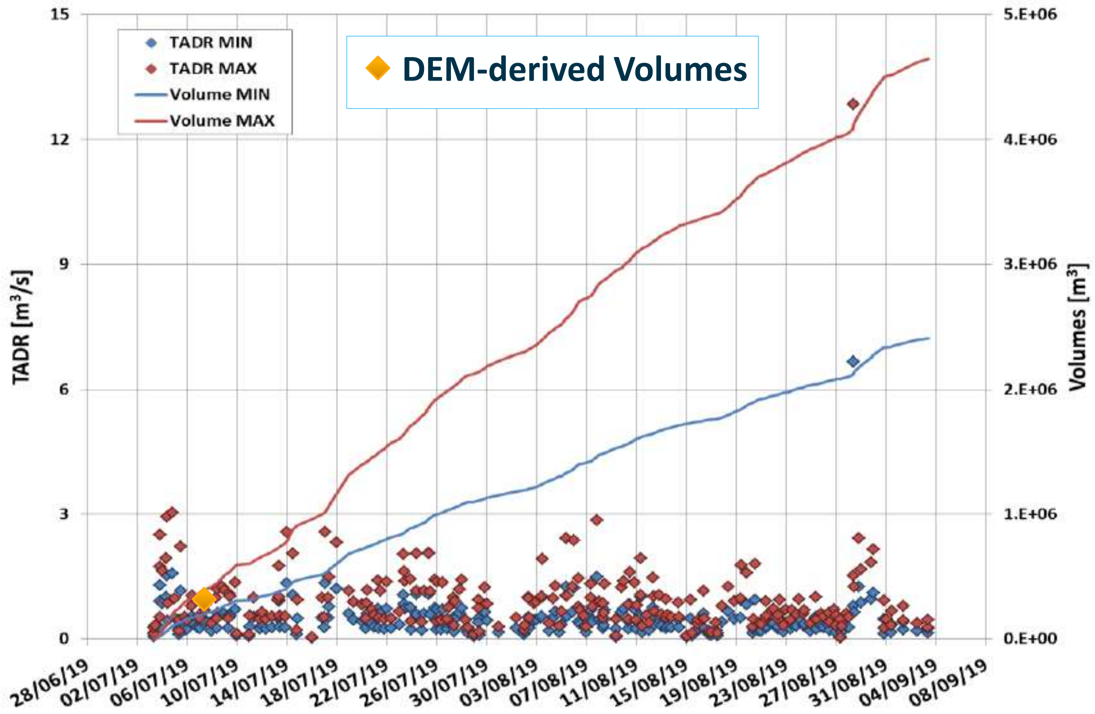
Ganci et al., 2019 Data, doi:10.3390/data4030120

Case study: Stromboli 2019 eruption

Pléiades triplets acquired on:

- 14 June 2019
- 9 July 2019
- 11 August 2019
- 08 October 2019





DSM difference between 9 July 2019 and 14 June 2019

Case study: Stromboli 2019 eruption

Pléiades triplets acquired on:

- 14 June 2019
- 9 July 2019
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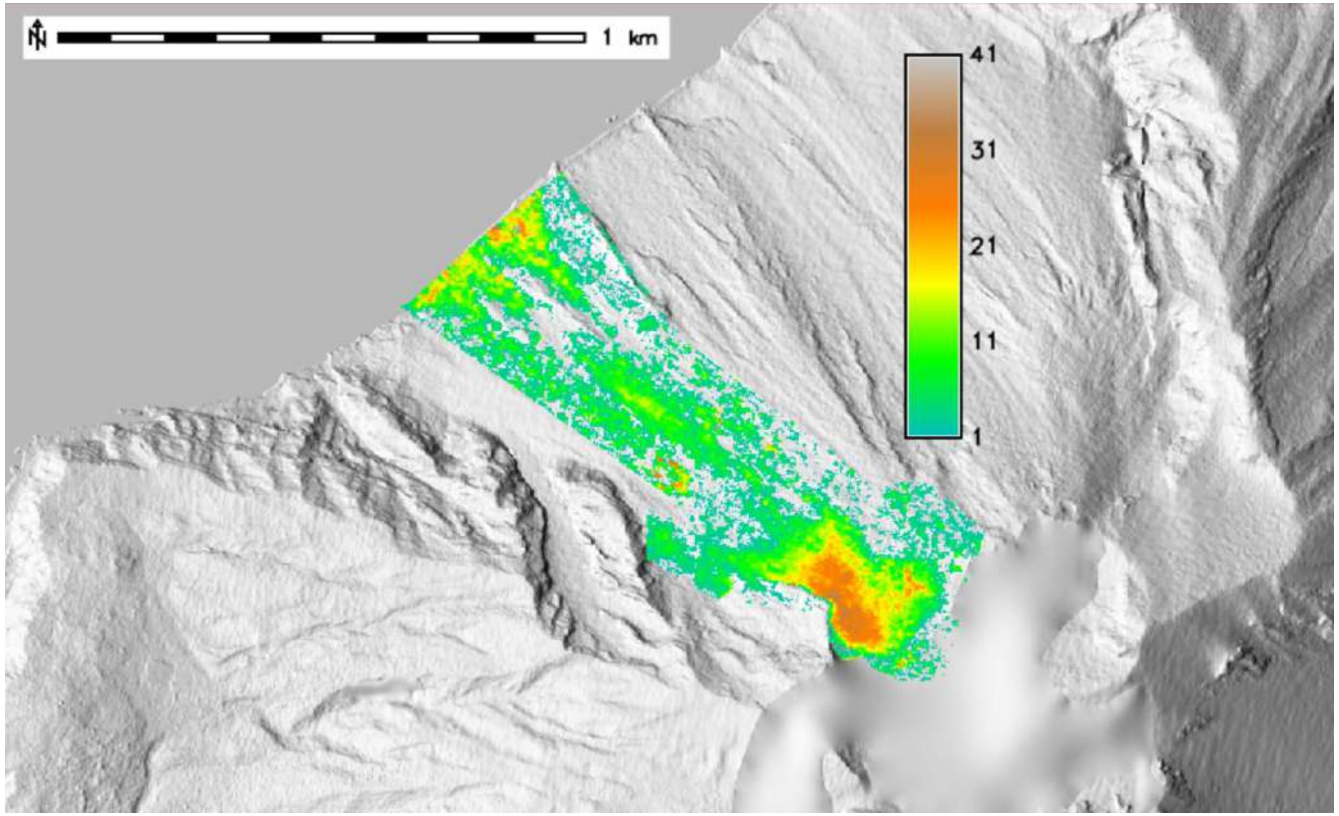
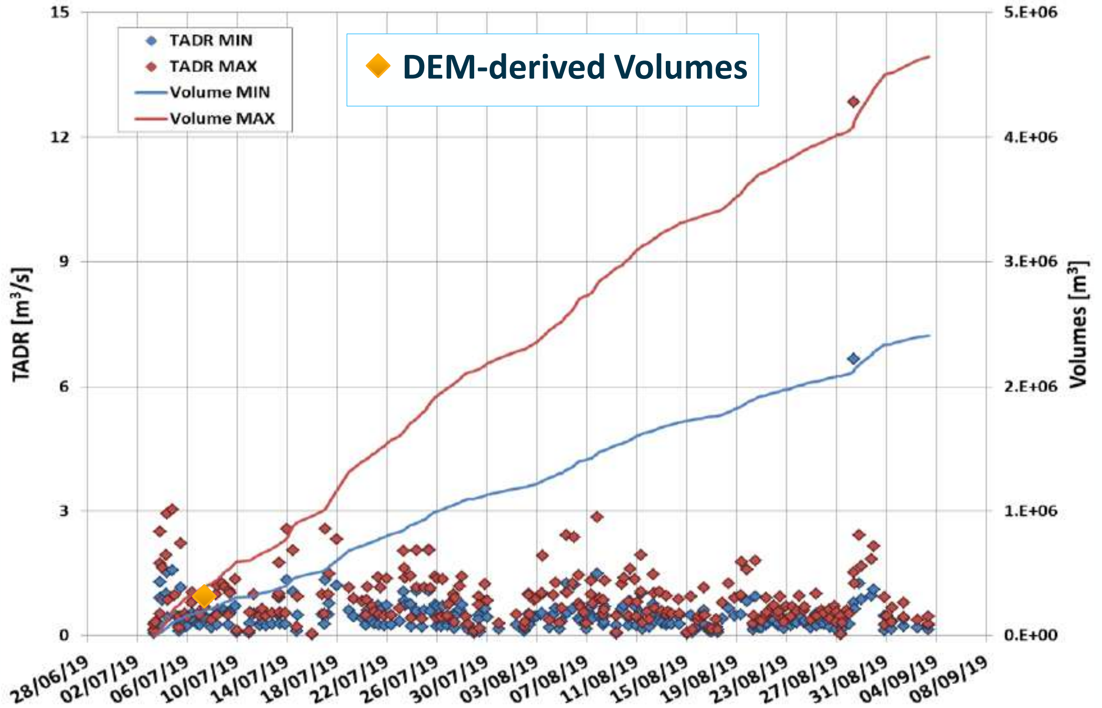
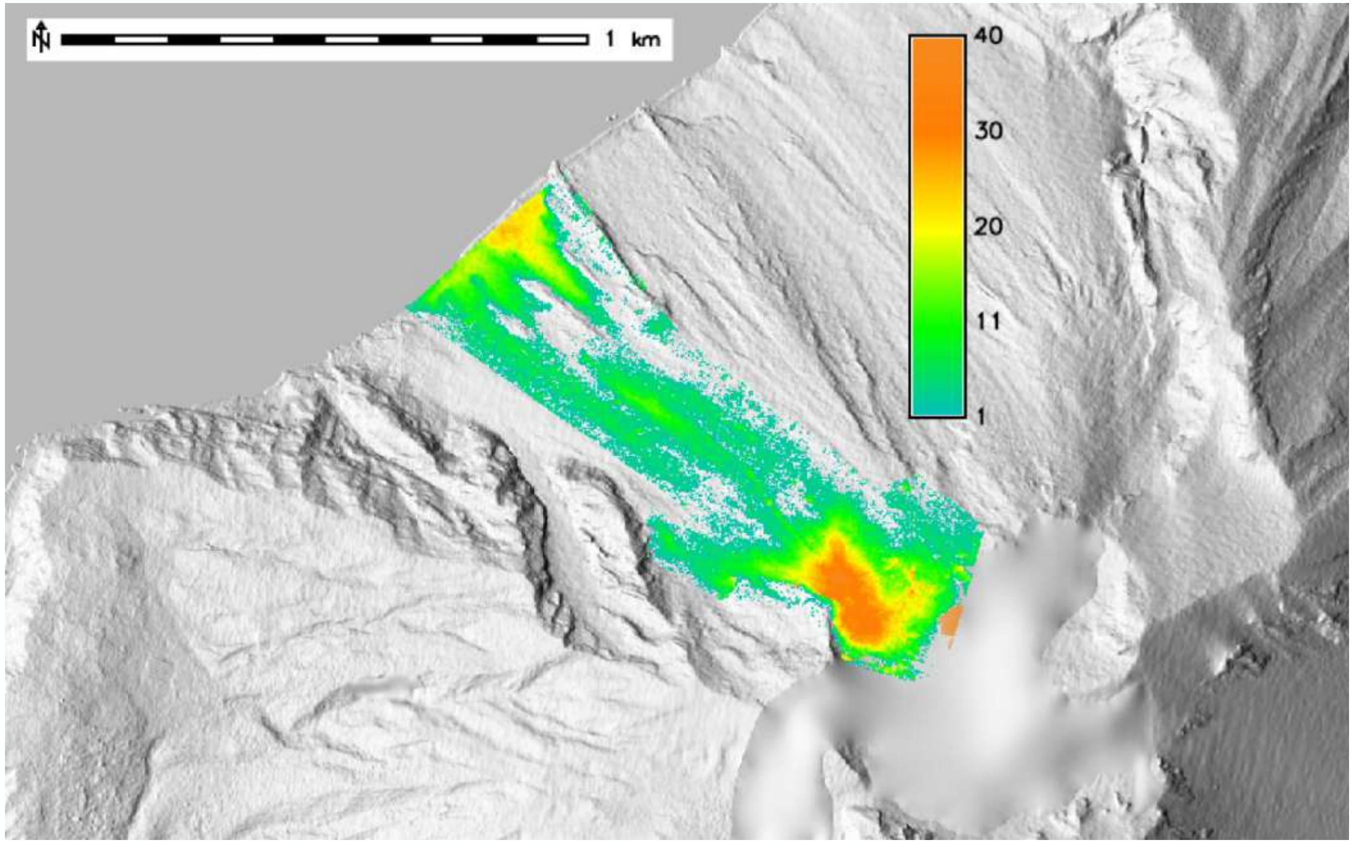


DSM difference between 11 August 2019 and 14 June 2019

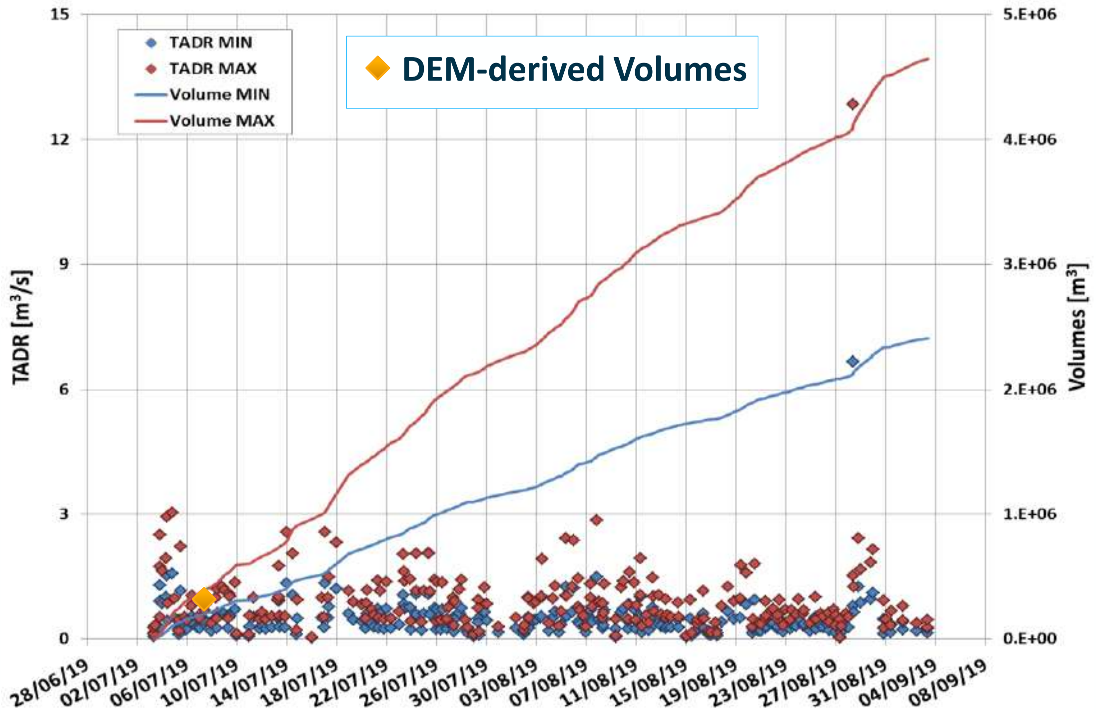


Case study: Stromboli 2019 eruption

Pléiades triplets acquired on:
- 14 June 2019
- 9 July 2019
- 11 August 2019
- 08 October 2019



DSM difference between 8 October 2019 and 14 June 2019



CONCLUSIONS & FUTURE TRENDS

- Satellite remote sensing is becoming an increasingly essential component of volcano monitoring.
- High temporal resolution IR satellite images (i.e. SEVIRI, MODIS, SLSTR, VIIRS) can provide thermal monitoring of active volcanoes, even if partially covered by clouds.
- The double view from SENTINEL 3 SLSTR can provide a more reliable sub-pixel level thermal information.
- Topographic monitoring obtained from high resolution satellite images acquired in tri-stereo or in multi-view provide limits and range of admissible values to the IR-based estimates.
- Information redundancy coming from the integration of different kinds of satellite data can reduce the total uncertainty.
- More data and case studies should be investigated
- Higher resolution multi-view images (i.e. WorldView 3, Pleiades Neo?) would be required

THANK YOU!