Thermal Remote Sensing for Global Volcano Monitoring

Diego Coppola

Dipartimento di Scienze della Terra – Università di Torino

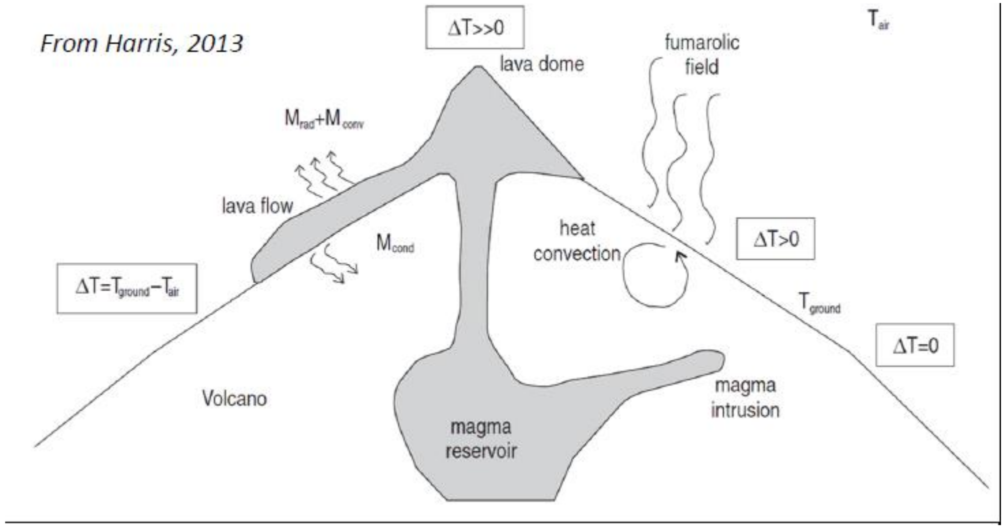
PART I: Basics of volcano thermal remote sensing: principles, sensors and hotspot detection systems

PART II: Operational / applications: how to interpret the MIROVA data for volcano monitoring

Volcanic phenomena are always accompanied by the transfer of heat from the earth crust into the atmosphere.

Part of this heat can be detected by space thus providing a robust way to monitor volcanoes.

- detect signs of **unrest** at quiescent volcanoes
- detect (start/end) of **eruption**
- follow the **evolution** of an eruption
- estimate **effusion rate** and **erupted volumes**
    - *Seismicity*
    - *Degassing*
    - *Deformation*



From Harris, 2013

Fundamental Laws

Planck Law

$$L(T,\lambda) = \frac{2hc^2}{\lambda^5(exp(hc/k\lambda T) - 1)}$$

It describes the spectral radiance as a function of the temperature of the object and the wavelength

Wien Law

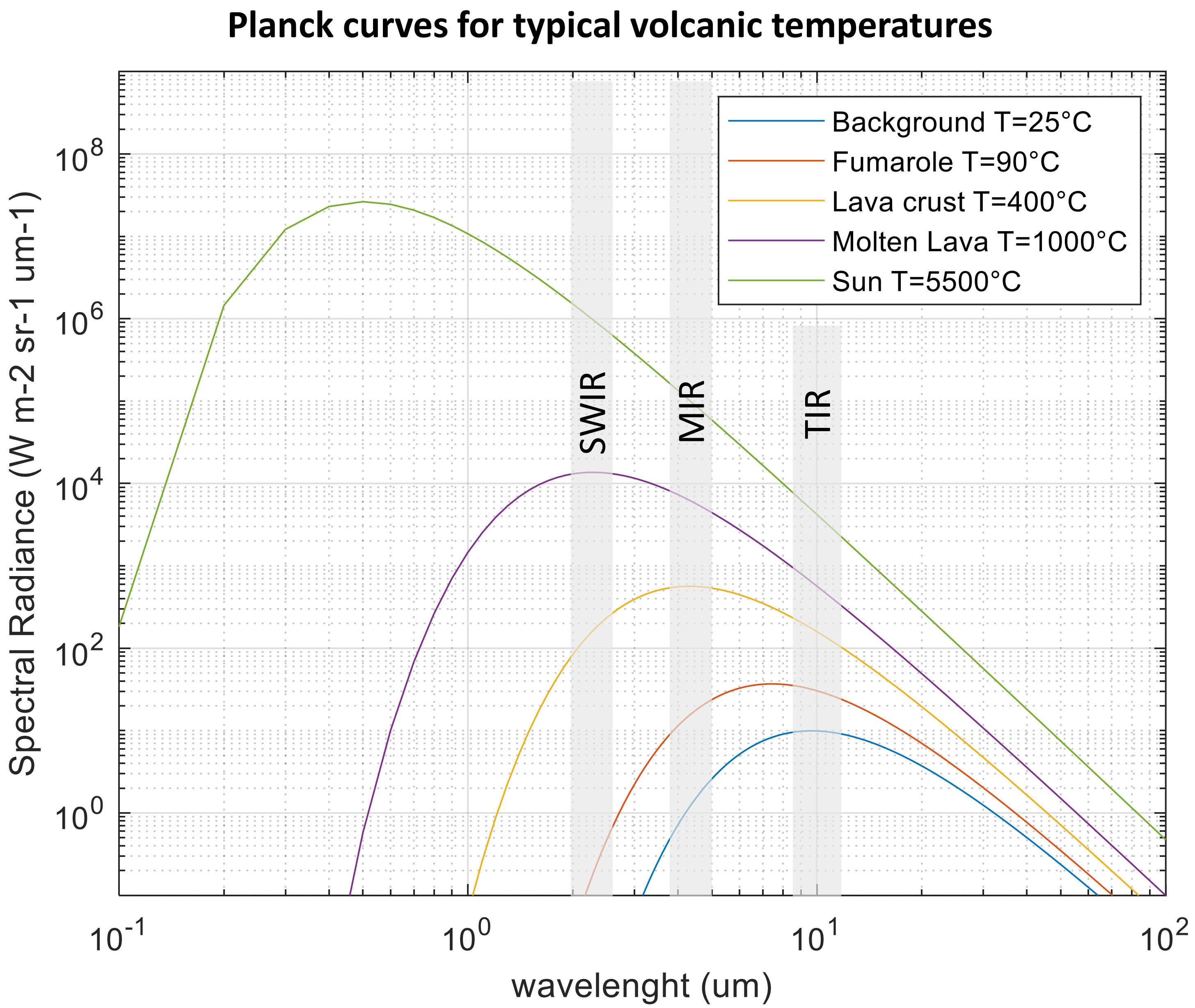
$$\lambda_{max} = \frac{A}{T}$$

It allows you to calculate the peak wavelength given the temperature of the object.

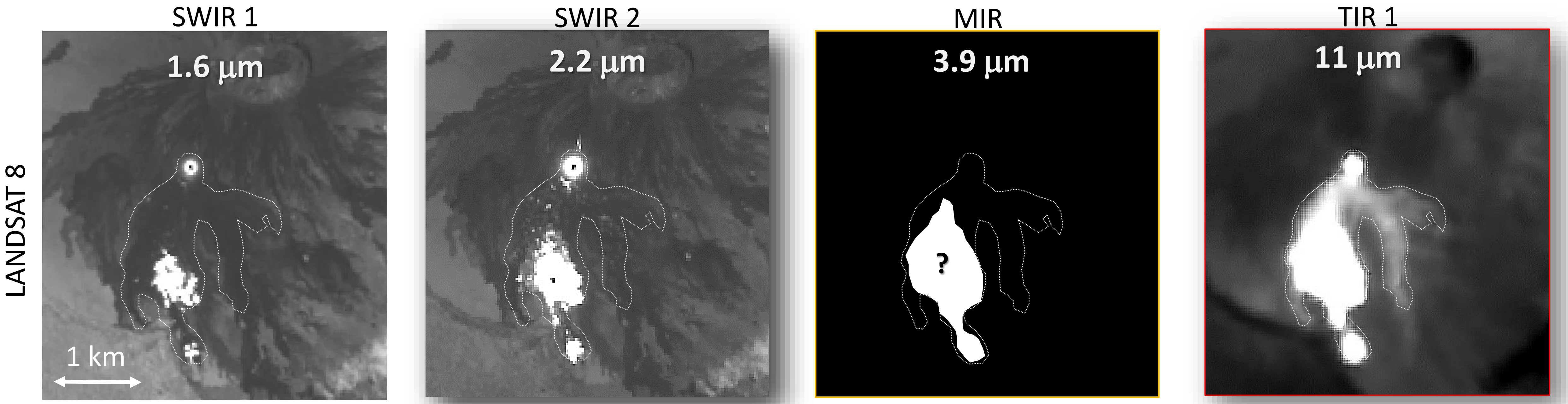
Stephan-Boltzmann Law

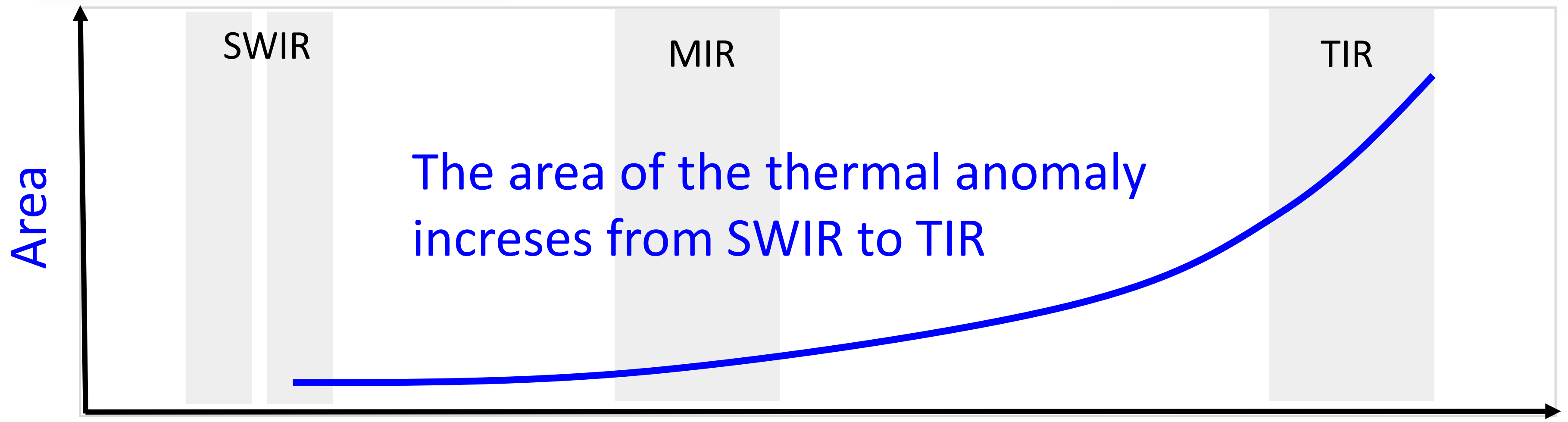
$$M = \sigma T^4$$

It allows you to calculate the emittance of a black body (W / m2), given its temperature. Represents the integral of the Planck curve.

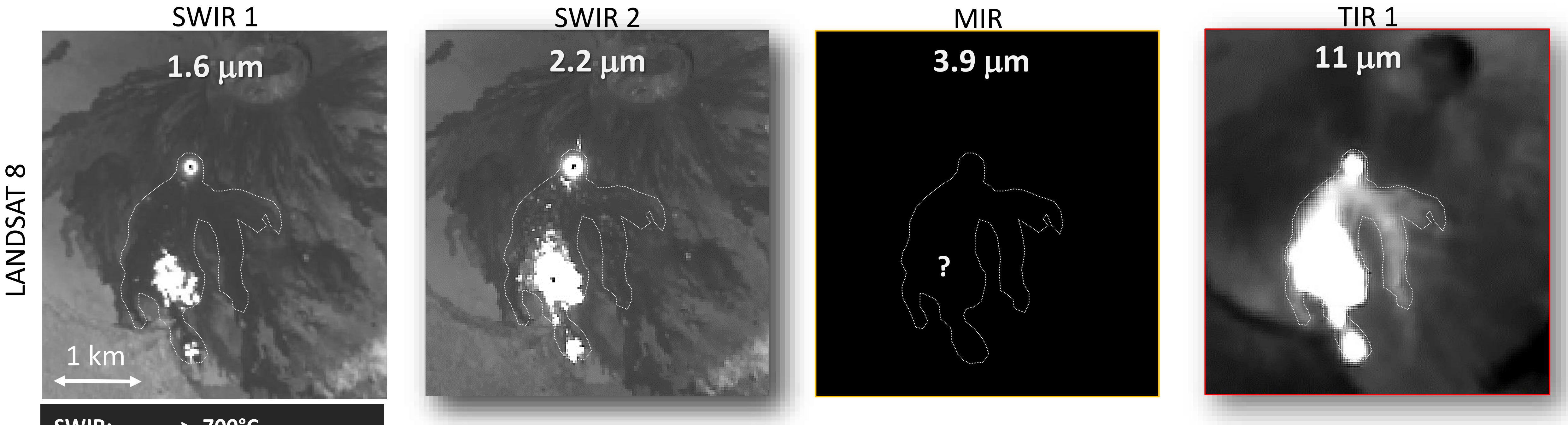


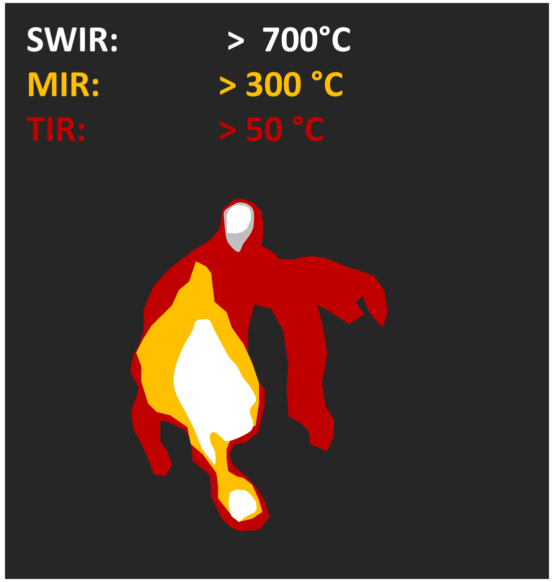
Different wavelengths «sense» different portion of a lava field

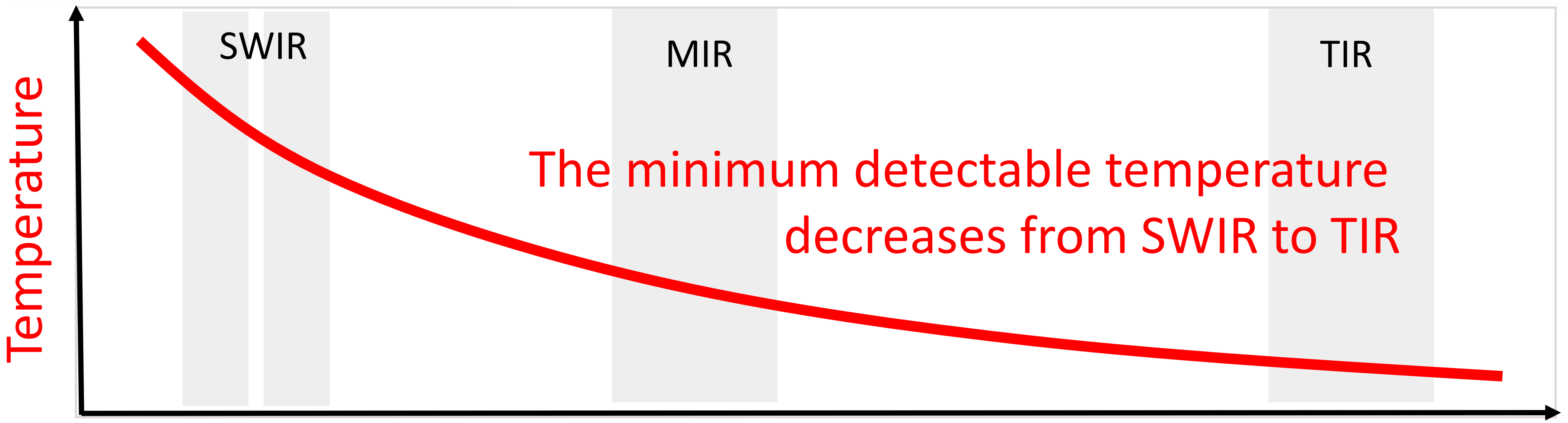




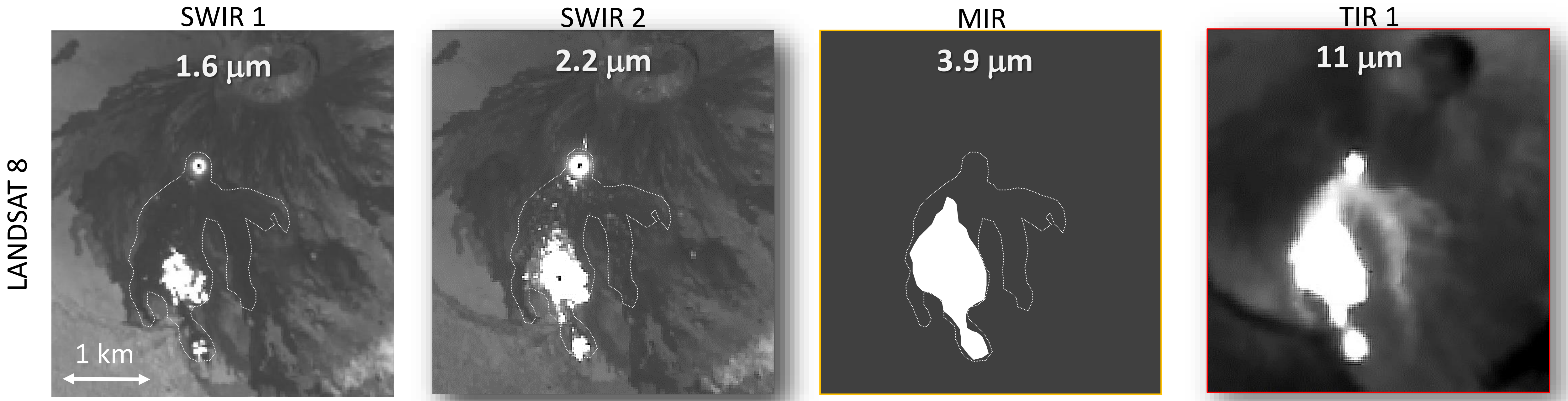
Different wavelengths «sense» portion of a lava field at different temperatures

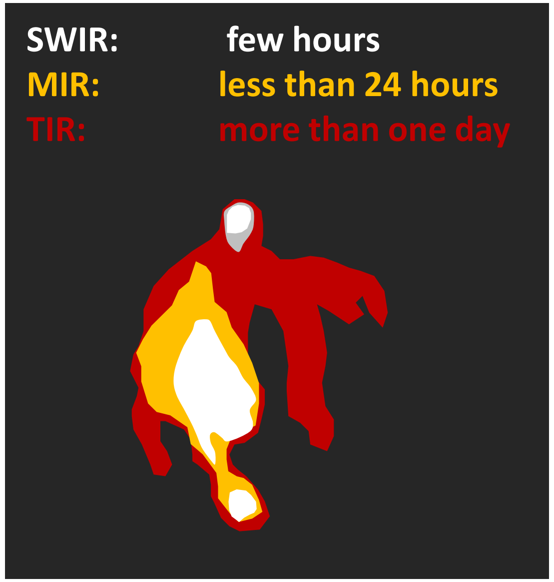




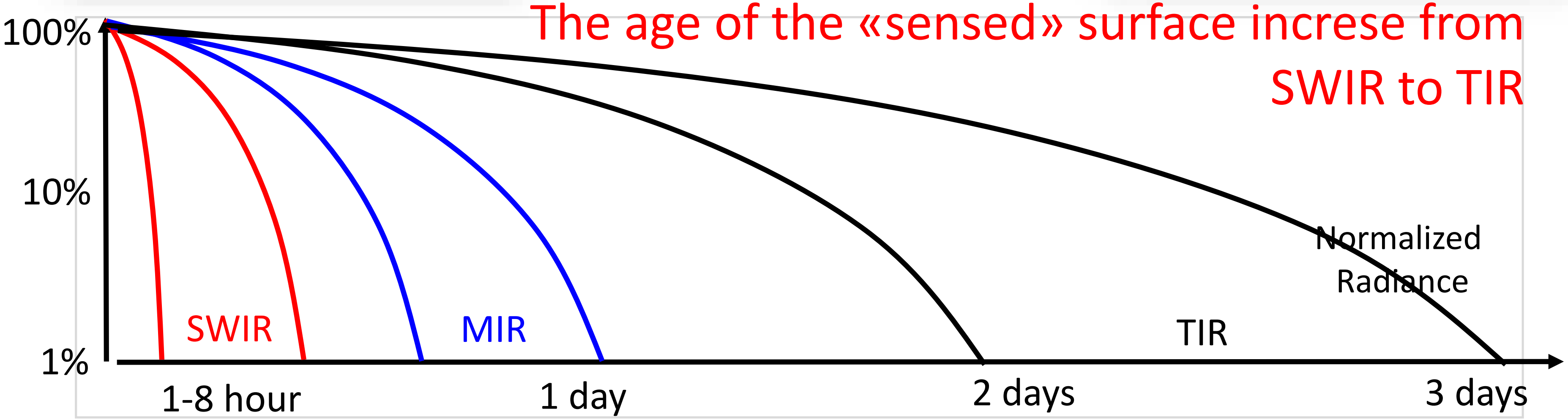


Different wavelengths «sense» portions of a lava field with different ages





The age of the «sensed» surface increse from SWIR to TIR



Pixel Integrated Radiance

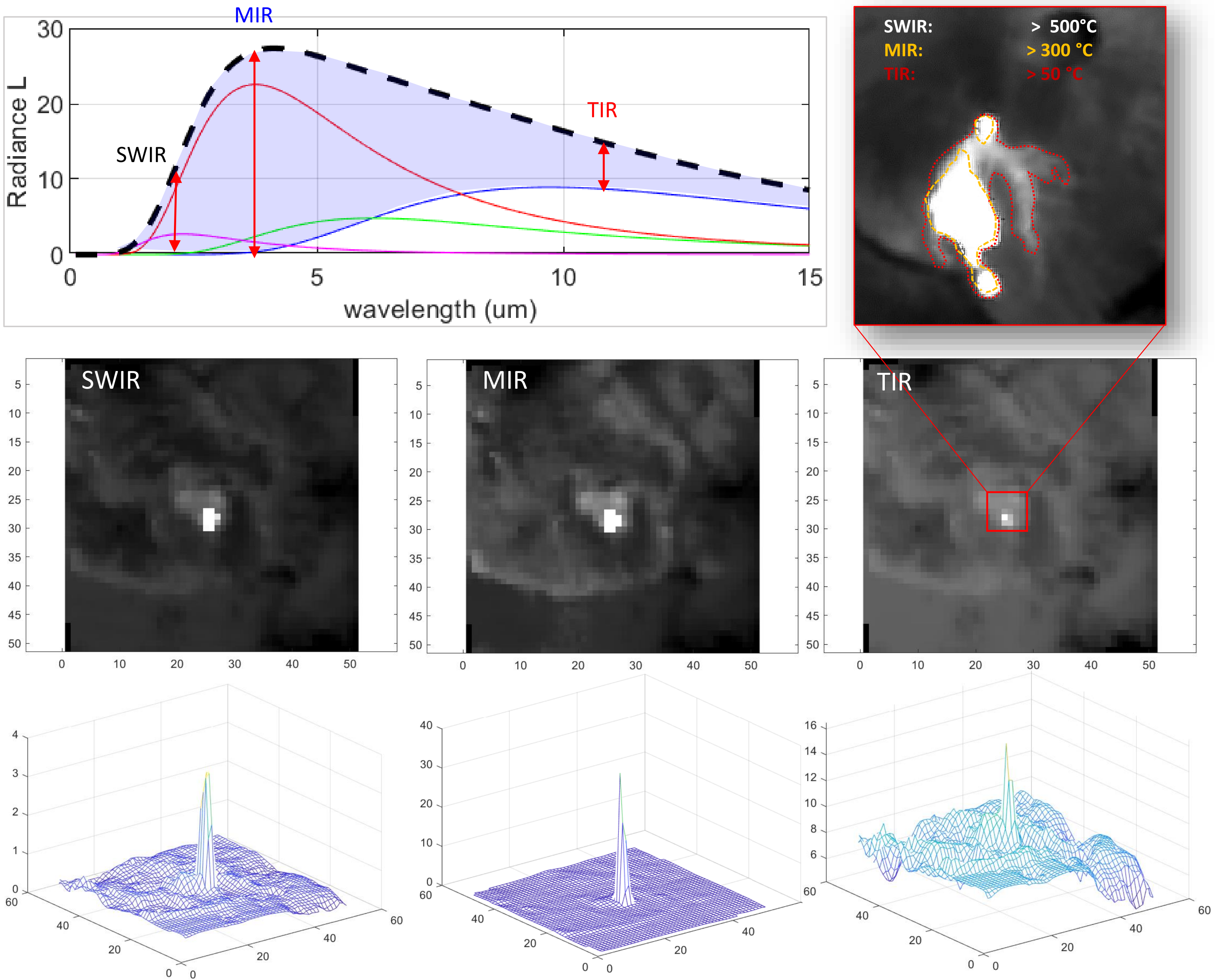
$$L(\lambda, T_{int}) = \sum_{i=1}^{n} f_i \cdot L(\lambda, T_i)$$

Is composed of the weighted sum of one or more radiant objects (hotspots) that do not entirely occupy the area of a pixel, but only a fraction of it.

Pixel integrated radiance depends

$$f_i = \frac{A_i}{A_{pix}}$$

- Temperature of each component (T_i)
- Area of the each component (A_i)
- Pixel size (A_{pix})
- Wavelegth (λ)
- Saturation



Excess Radiance

$$\Delta L(\lambda) = L(\lambda, T_{int}) - L(\lambda, T_{bk})$$

Is calculated as the difference between the brightness temperature of the hotspot-contaminated pixel, and the background pixel:.

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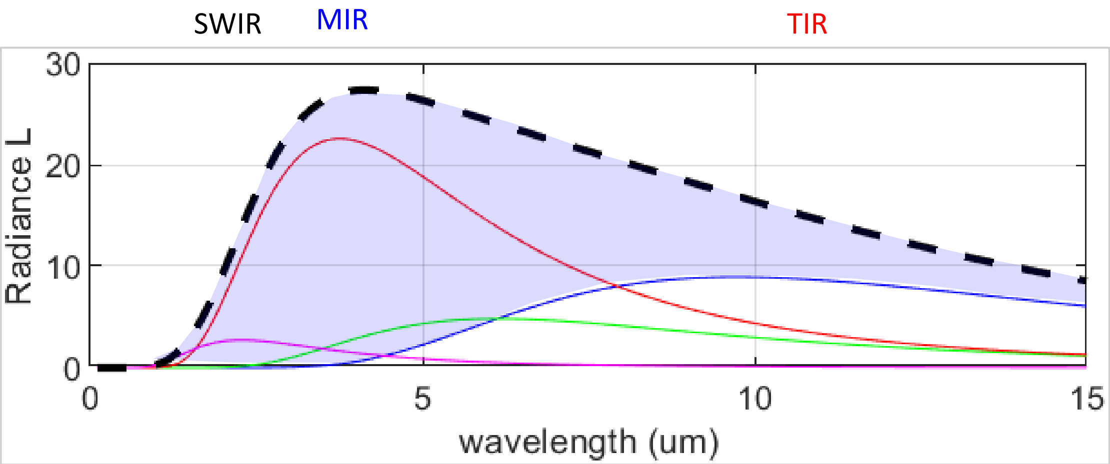

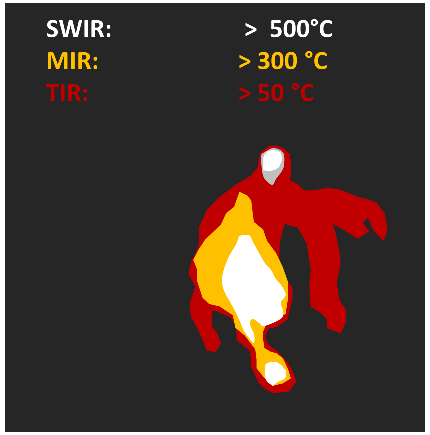

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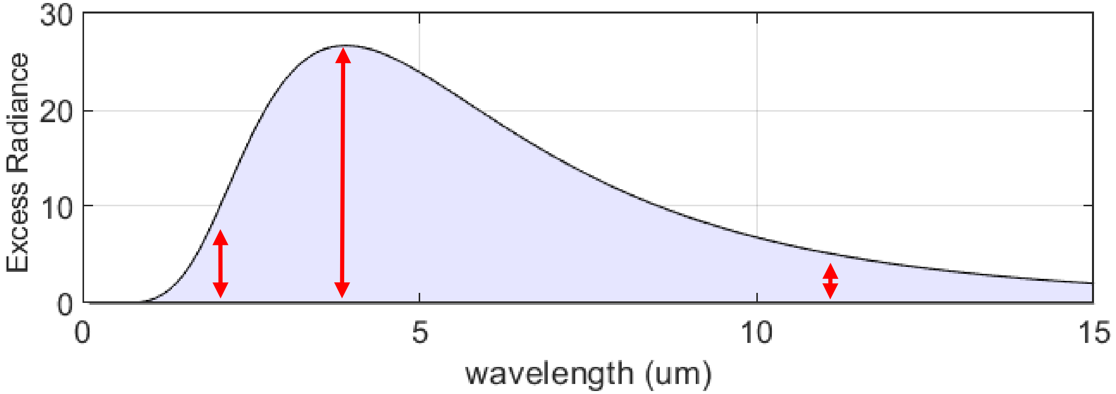
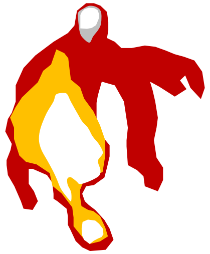




Radiative Power

$$VRP_{true} = \sigma\varepsilon \sum_{i=1}^{n} A_i \cdot (T_i^4 - T_{bk}^4)$$

The true heat flux radiated by the hotspot is also composed of the weighted sum of one or more sub-pixel radiant objects.

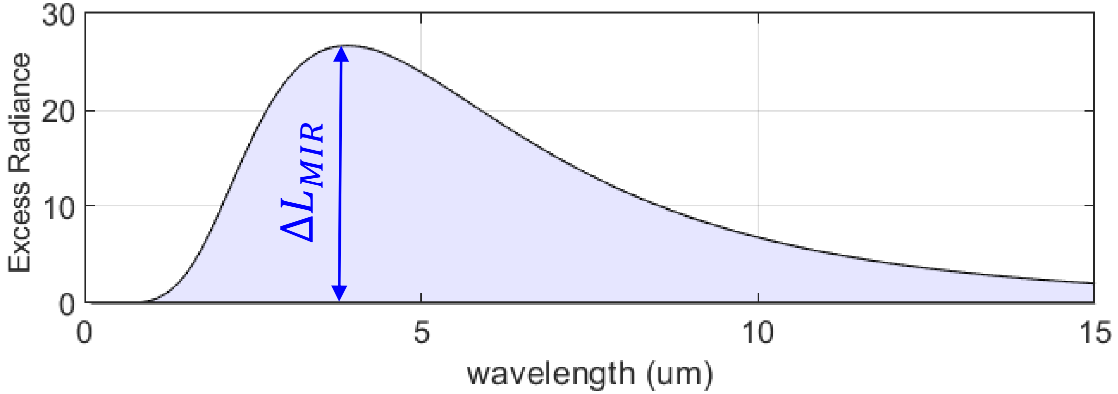
$$\Delta L(\lambda) = L(\lambda, T_{int}) - L(\lambda, T_{bk})$$

RP_{true}

Excess MIR Radiance

$$\Delta L(MIR) = L(MIR, T_{int}) - L(MIR, T_{bk})$$

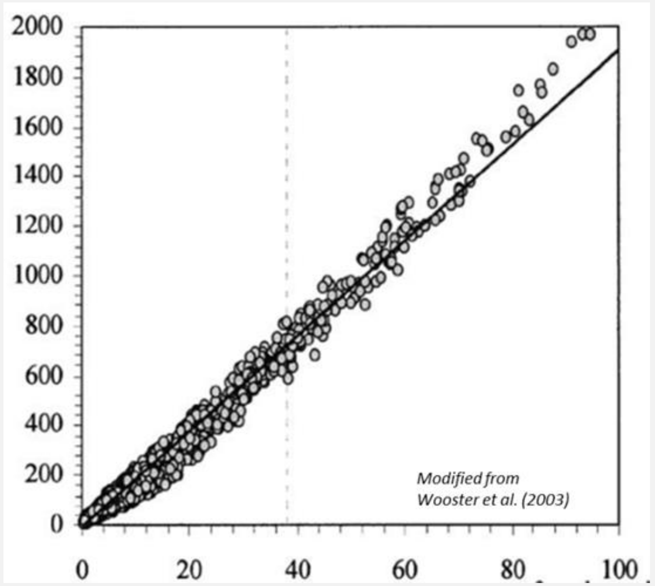
Is calculated as the difference between the MIR radiance of the hotspot-contaminated pixel, and the background pixel:.

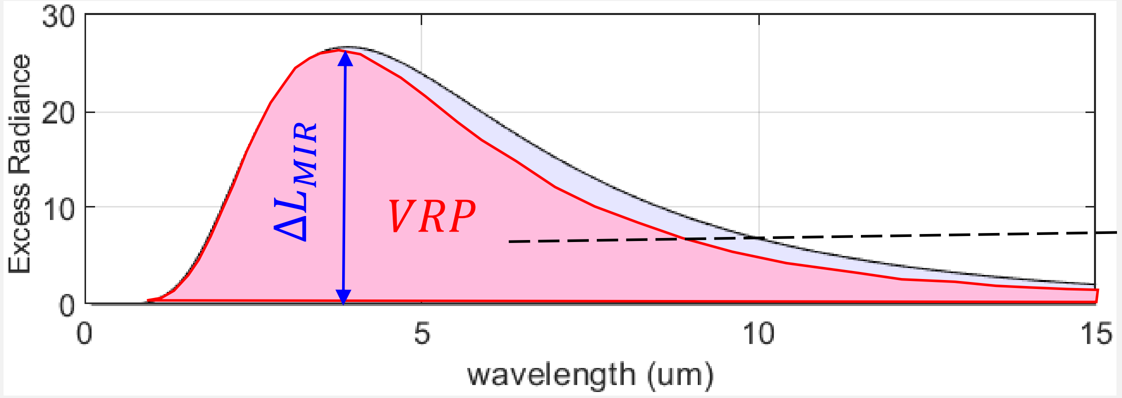


Areas considered for RP_{true}

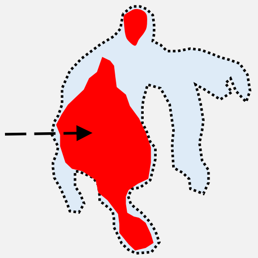
Volcanic Radiative Power

$$VRP = 18.9 \cdot A_{pix} \cdot \Delta L_{MIR}$$



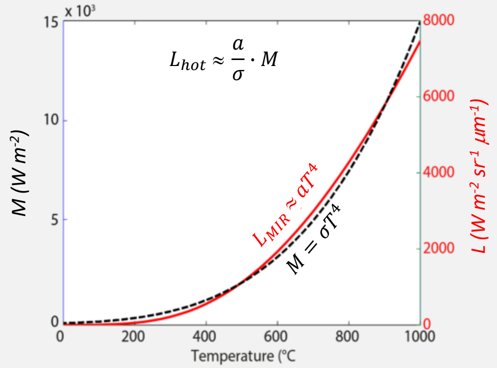


Areas considered for VRP



The MIR-Method: Originally devlopped to calculate the *fire radiative power* (Wooster et al, 2003), this method allow to calculate the **radiant power of the hot (>200°C) and young (< 24 hours)** lava surfaces directly from the "*excess MIR radiance*".

KEY POINT*:* the MIR radiance of an hot object at T>200°C is almost proportional to T^4, as the Stephan-Boltzmann law.



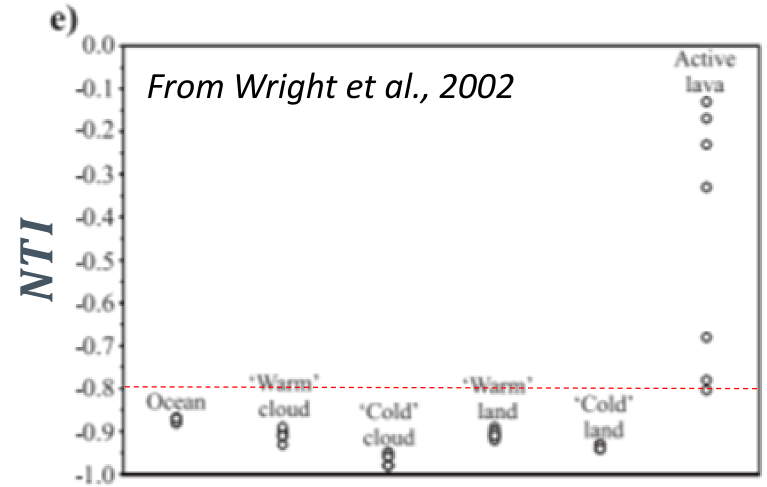
Hotspot detection

Most of the hotspot detection algorithms exploit the different radiance recorded in two or more distinct bands.

One of the most used indexes in this sense is the *Normalized Thermal Index* (Wright et al., 2002) which uses the MIR and TIR bands:

$$NTI = \frac{L_{MIR} - L_{TIR}}{L_{MIR} + L_{TIR}}$$

Setting a threshold is crucial for detecting a hotspot.



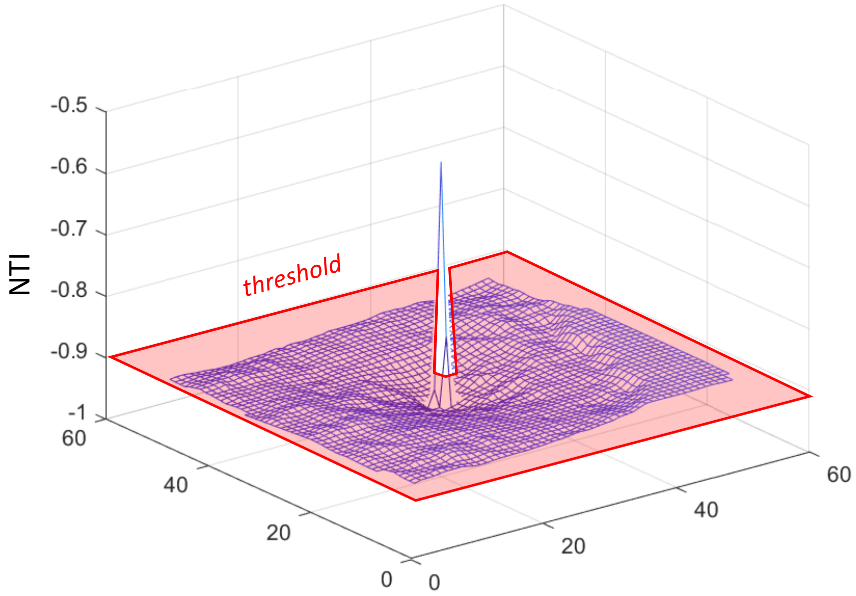
The threshold can be:

FIXED: a fixed value set for local or global application

CONTEXTUAL: the index exceed the value of neighbour pixel

TEMPORAL: the index exceed the normal temporal variability

HYBRID: a mix of the above



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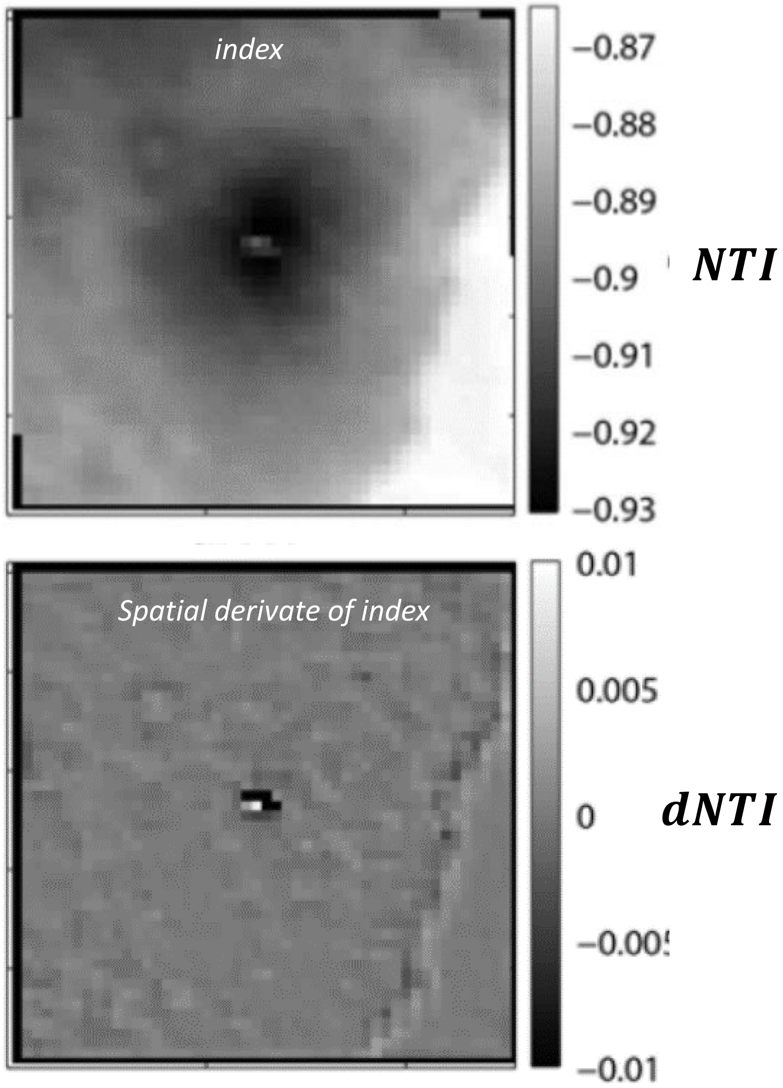

From Coppola et al., 2016

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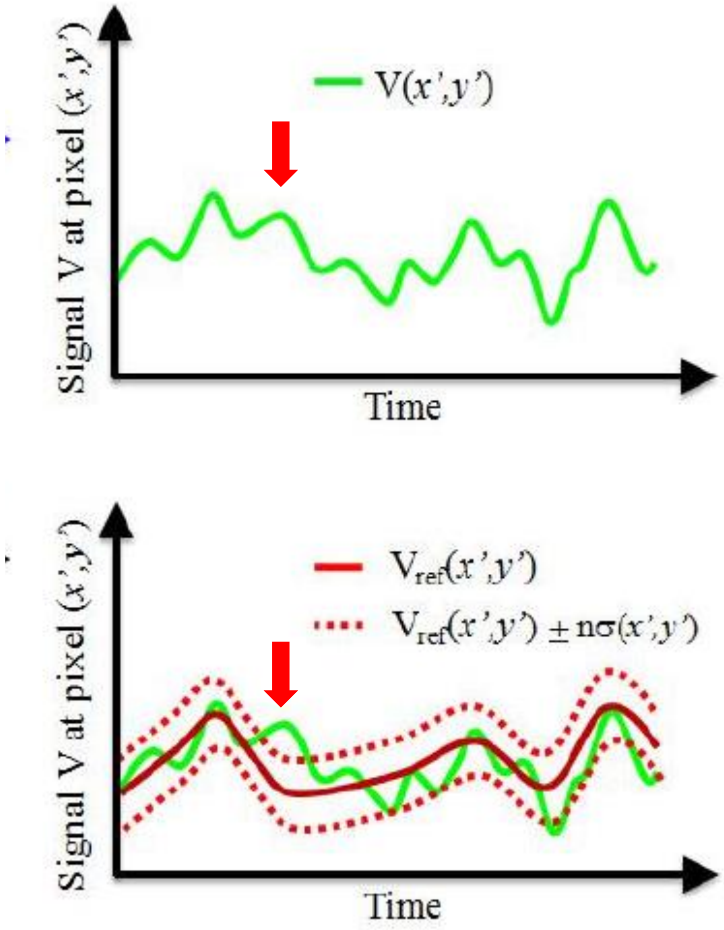

From Marchese et al., 2010

Hotspot detection

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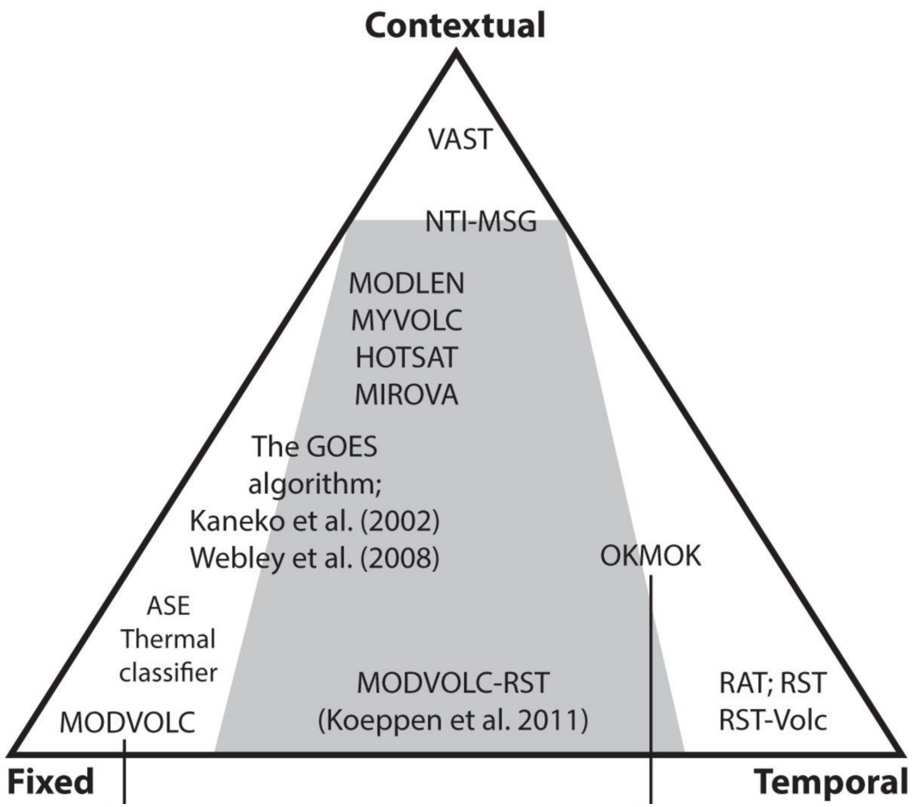


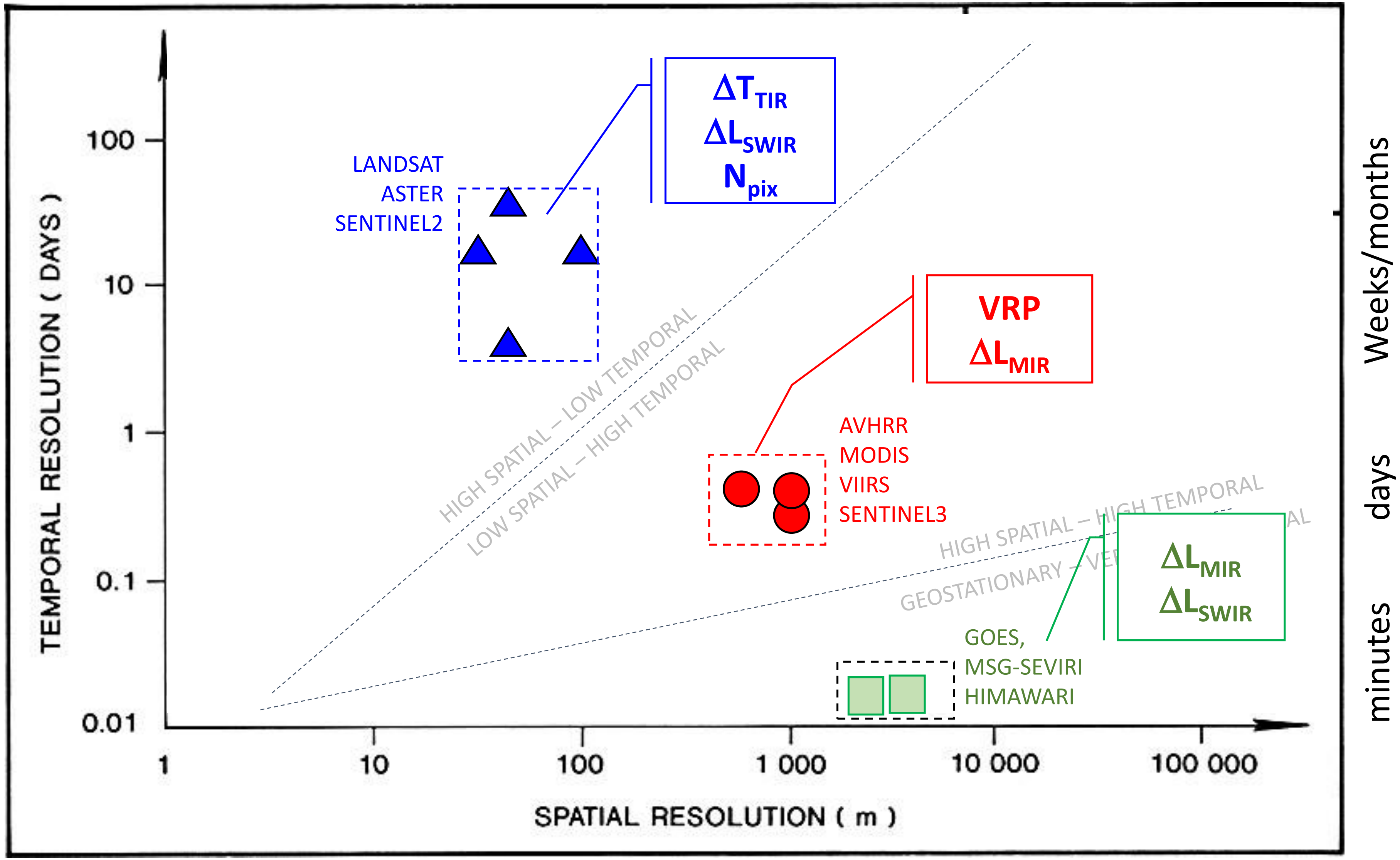
From Harris et al., 2016

Common Metrics used quantify volcanic thermal anomalies

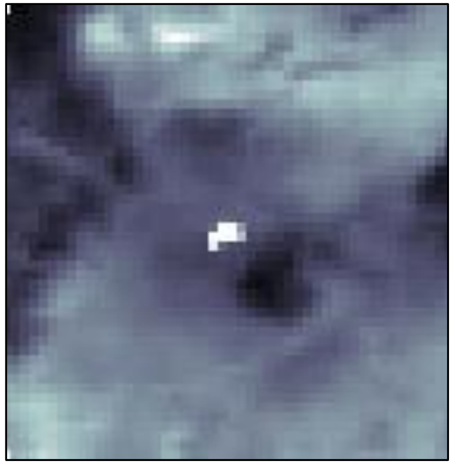
Depending on the sensor (wavelenght, resolutions) and algorithm, there several metric used:

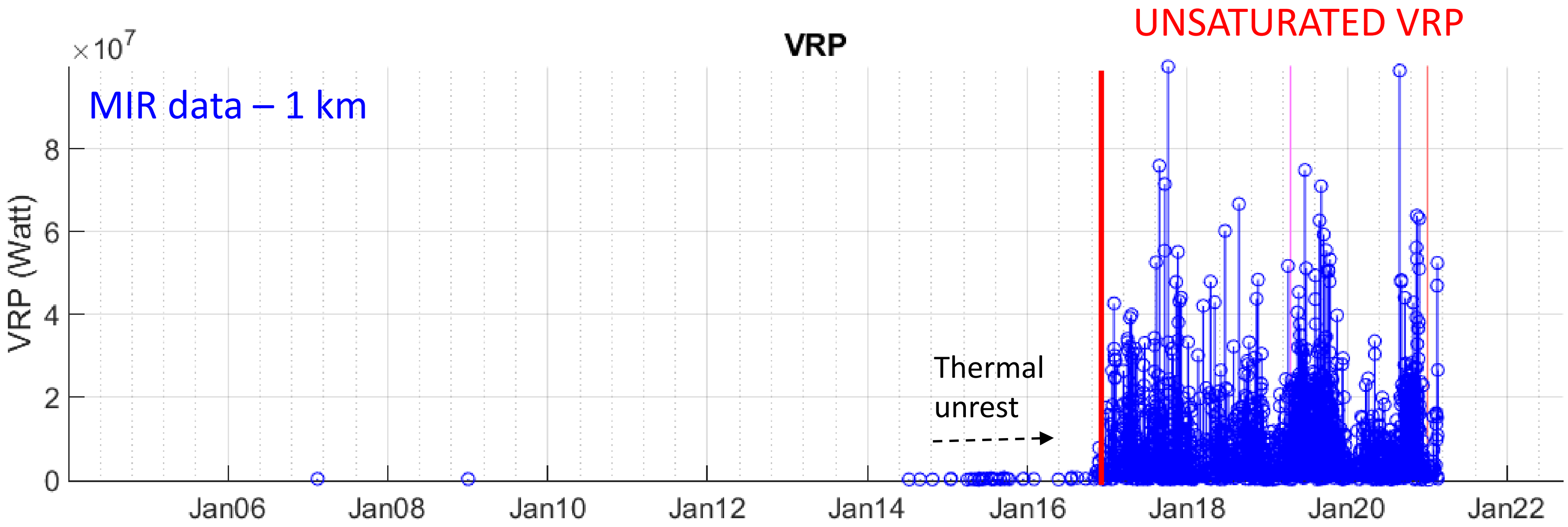
Parameter	Unit	Proxy	Dependency	quantitative
1. Number of pixels (Npix)	counts	Size/intensity	Pixel size, wavelength	NO*
2. Excess Temperature (ΔT)	K	Size/intensity	Pixel size, wavelength, saturation	NO*
3. Excess Radiance (ΔL) ➢ *Area* ➢ *Temperature* • ***TADR (only effusive)***	W m^{-2} sr^{-1} μm^{-1} m^2 K $m^3 s^{-1}$	Size /Intensity Area Temperature Mass flux	Pixel size, wavelength, saturation	YES*
4. Volcanic Radiative Power (VRP) • ***TADR (only effusive)***	Watt $m^3 s^{-1}$	Radiant Flux Mass flux	method	YES*

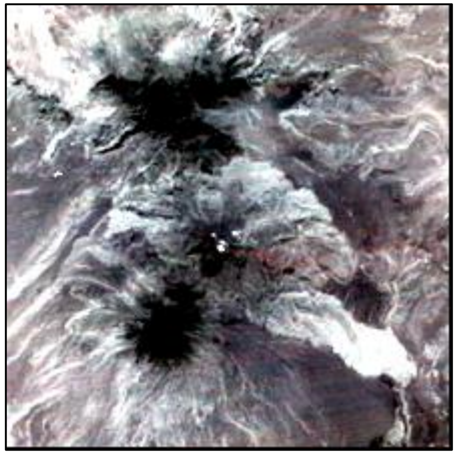
Common Sensors used for thermal monitoring of volcanoes

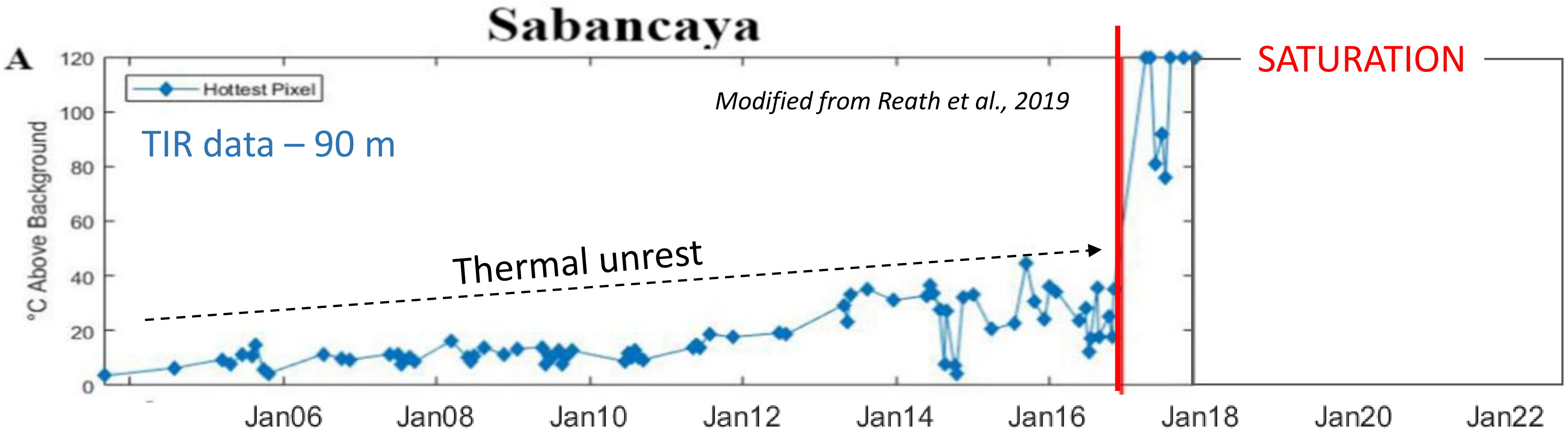


Different sensors or resolutions → different type of data usage and application



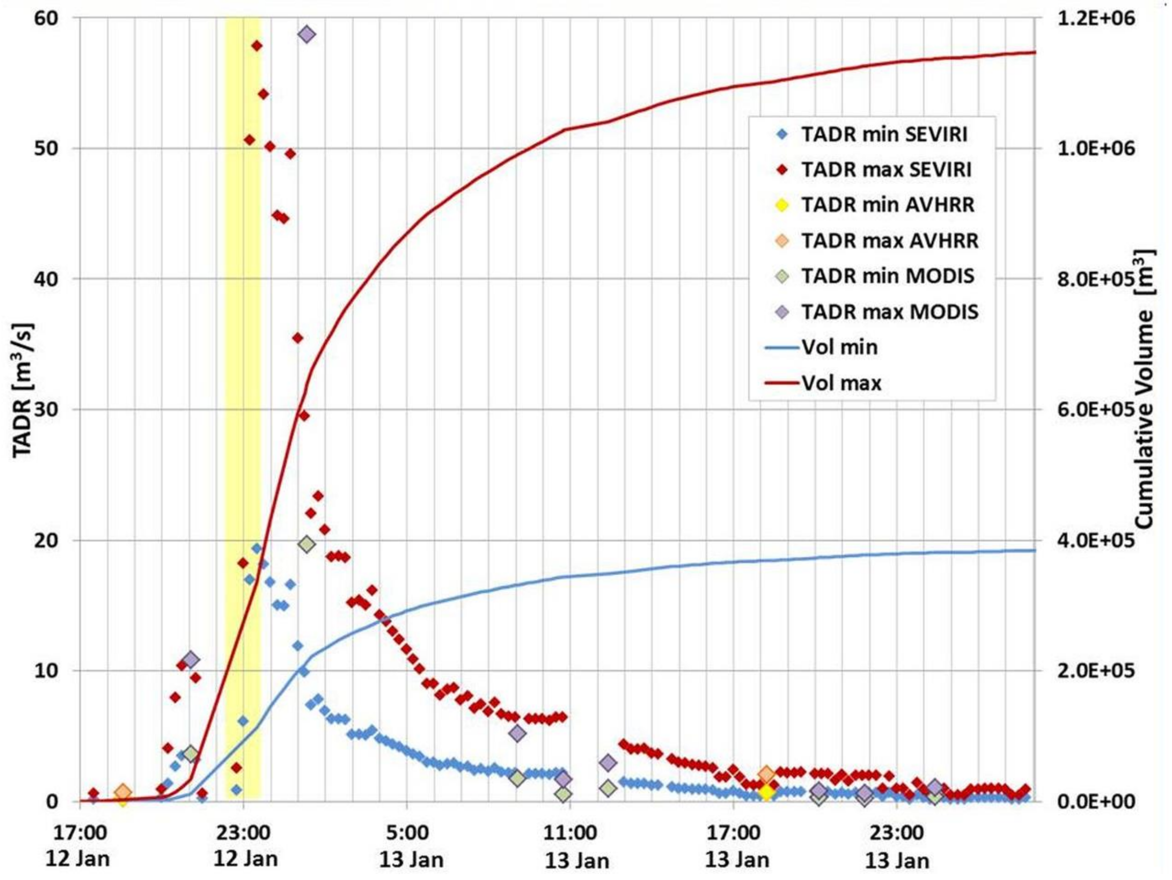




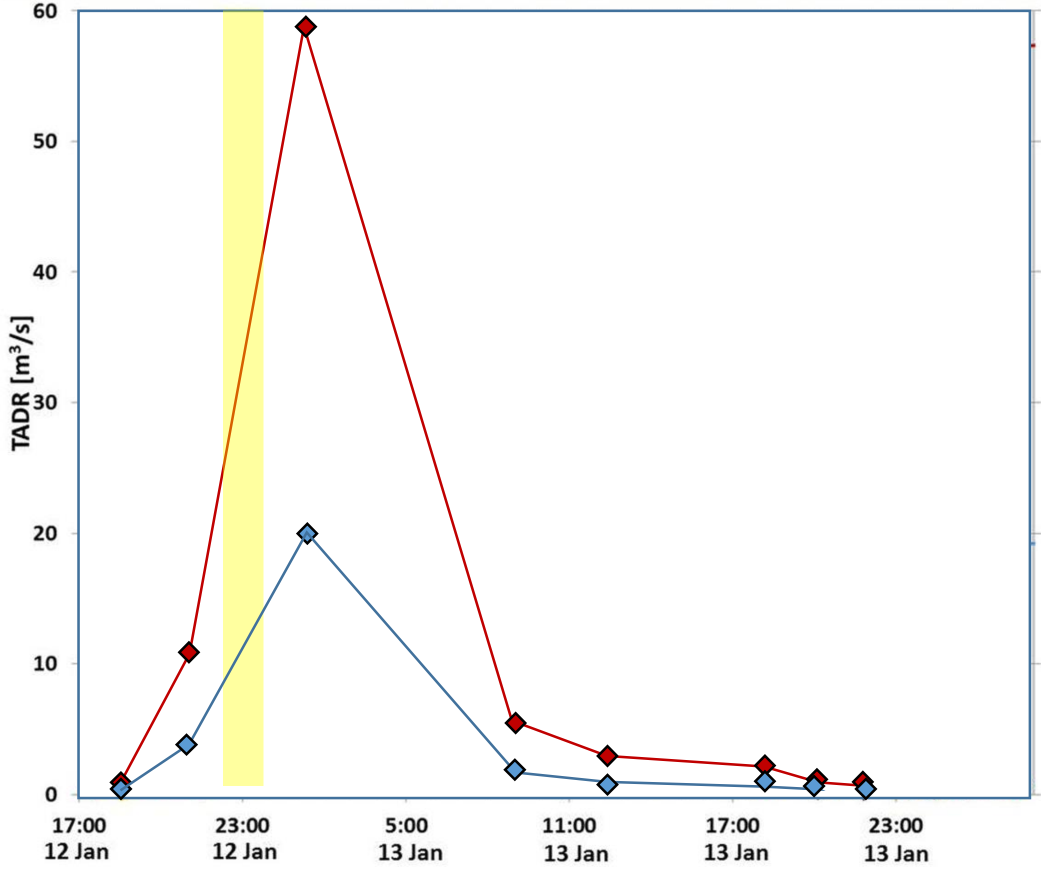


Different sensors or resolutions ➔ different type of data usage and application

MSG-SEVIRI 15 min



MODIS ~12 hours



Modified from Ganci et al., 2016

	Developper	System	Sensor	Bands	Spat. Res.	Temp. Res.	Coverage	Website	Images	metric	Timeseries	Reference
LOW RES	LMV	HOTVOLC	SEVIRI	MIR,TIR	~ 5 km	15-30 min	Specific Targets Europe, Africa	http://hotvolc.opgc.fr/www/index.php	x	ΔL	x	Gouhier et al., 2016
	HIGP	-	GOES	MIR, TIR	~ 5 km	15-30 min	North, Central, South America; Pacific Ocean	http://goes.higp.hawaii.edu/	x			Patrick et al., 2016
	USGS	VOLCVIEW	AVHRR/MODIS/ VIIRS/GOES	MIR,TIR	~1km/~5 km	6-12 h/15-30 min	Specific Targets Alaska; Aleutines; Kamchatka;Pacific Ocean	https://volcview.wr.usgs.gov/	x			Shneider et al., 2014
	INGV	HOTSAT	MODIS/SEVIRI	MIR,TIR	~1km/~5 km	6-12 h/15-30 min	Specific Targets Europe, Africa	Internal use		ΔL		Ganci et al., 2011
	INGV	AVHotRR	AVHRR/SEVIRI	MIR,TIR	~1km/~5 km	6-12 h/15-30 min	Specific Targets	Internal use				Lombardo et al., 2016
	INGV	**MS2RWS**	**SEVIRI**	**MIR,TIR**	**~ 5 km**	**5 min**	**Specific Targets Europe, Africa**	**http://160.97.1.28/rapidresp/**	**x**	**ΔL**	**x**	***Corradini, Buongiorno***
MOD RES	IMAA	RSTvolc	AVHRR/MODIS	MIR, TIR	~ 1 km	6-12 h	Specific Targets	Intarnal use				Pergola et al., 2016
	AVO	-	AVHRR/MODIS/VIIRS	MIR,TIR	350 m/~ 1 km	6-12 h	Specific Targets Alaska; Aleutines; Kamchatka	http://avo.images.alaska.edu/tools/ftp_browser.php	x			Dean et al., 2002
	HIGP	MODVOLC	MODIS	MIR, TIR	~ 1 km	6-12 h	Global	http://modis.higp.hawaii.edu/		VRP	x	Wright et al., 2004
	UNITO	**MIROVA**	**MODIS /SENTINEL2**	**MIR, TIR**	**~ 1 km**	**6-12 h**	**Specific Targets - Global scale**	**http://www.mirovaweb.it/**	**x**	**VRP**	**x**	**Coppola et al., 2016**
	KVERT	VOLSATVIEW	AVHRR/MODIS/VIIRS	MIR, TIR	~ 1 km	1-2 h	Specific Targets - Kamchatcka&Kuriles	http://volcanoes.smislab.ru/static/index.sht	x			Gordeev et al., 2016
	UNI TOKYO	REALVOLC	MODIS	MIR, TIR	~ 1 km	6-12 h	Specific Targets Asia;Oceania; North, Central, South America	http://vrsserv2.eri.u-tokyo.ac.jp/	x	ΔT	x	Kaneko et al., 2010
	NOAA	NIGHTFIRE	VIIRS	SWIR/MIR	~ 1 km	6-12 h	Global	https://ngdc.noaa.gov/eog/viirs/download_viirs_fire.html		VRP		Elvidge et al., 2013
	NASA	FIRMS	VIIRS/MODIS	MIR, TIR	350 m/~ 1 km	6-12 h	Global	https://firms.modaps.eosdis.nasa.gov/		VRP		Davies et al., 2009
HIGH RES	JPL	AVA	ASTER	TIR	~ 90 m	variable, typically > 16 days	Specific Targets - Global	https://ava.jpl.nasa.gov/	x			Linick et al., 2014
	GSJ	ASTER Image Database	ASTER	TIR	~ 90 m	variable, typically > 16 days	Specific Targets - Global	https://gbank.gsj.jp/vsidb/image/index-E.html	x			Urai (2011)
	Cornell University	AVTOV	ASTER	TIR	~ 90 m	variable, typically > 16 days	Specific Targets - Latin America	https://www.wovodat.org/		ΔT	x	Reath et al., 2019
	GFZ	**MOUNTS**	**SENTINEL 1-2-5P**	**SWIR**	**~ 20 m**	**5 days**	**Specific Targets - Global**	**http://mounts-project.com/home**	**x**	**Npix**	**x**	**Valade et al., 2019**
	UCN	VOLCANOMS	LANDSAT/SENTINEL2	SWIR	~20/30 m	5- 30 days	Specific Target	http://volcanoms.ckelar.org/	x	ΔL	x	*Layana et al., 2020*
	IMAA	**NHI TOOL**	LANDSAT/SENTINEL2	SWIR	~20/30 m	5- 30 days	Global	https://nicogenzano.users.earthengine.app/view/nhi-tool	x	ΔL	x	*Genzano et al., 2020*

UNIVERSITÀ DEGLI STUDI DI TORINO

MIROVA

Middle Infrared Observations of Volcanic Activity

DIPARTIMENTO DI SCIENZE DELLA TERRA DI TORINO

*a collaborative project between Earth Science Departments of Turin and Florence (Italy), on behalf of the Italian Civil Protection Department, for automatic thermal monitoring of **Stromboli** and **Etna** from space.*

*Now extended for monitoring more than 200 **volcanoes***

TEAM

D.Coppola, M Laiolo, C. Cigolini, F. Massimetti (PhD)

University of Turin

COLLABORATORS:

D. Delle Donne, M Ripepe

INGV, University of Florence

Other collaborators provided great improvement to previous and current version of the system:
Hidran Harias, Walter Vanzetti, Davide Piscopo, Stefano Zuliani, Alberto Franchi

NASA LANCE Fondazione CRT LGS Laboratorio Geofisica Sperimentale Protezione Civile Nazionale Università degli Studi Firenze

GOALS

APPLICATION

To detects, localize and **quantify thermal anomalies** sourced by volcanic activity

To provide near real time thermal observations of volcanic activity in **support of volcano monitoring**

RESEARCH

to improve our **understanding of volcano dynamics** for hazard evaluation and forecasting

to build and update a global **database of volcanic thermal emissions**

UNIQUE SYSTEM

MODIS

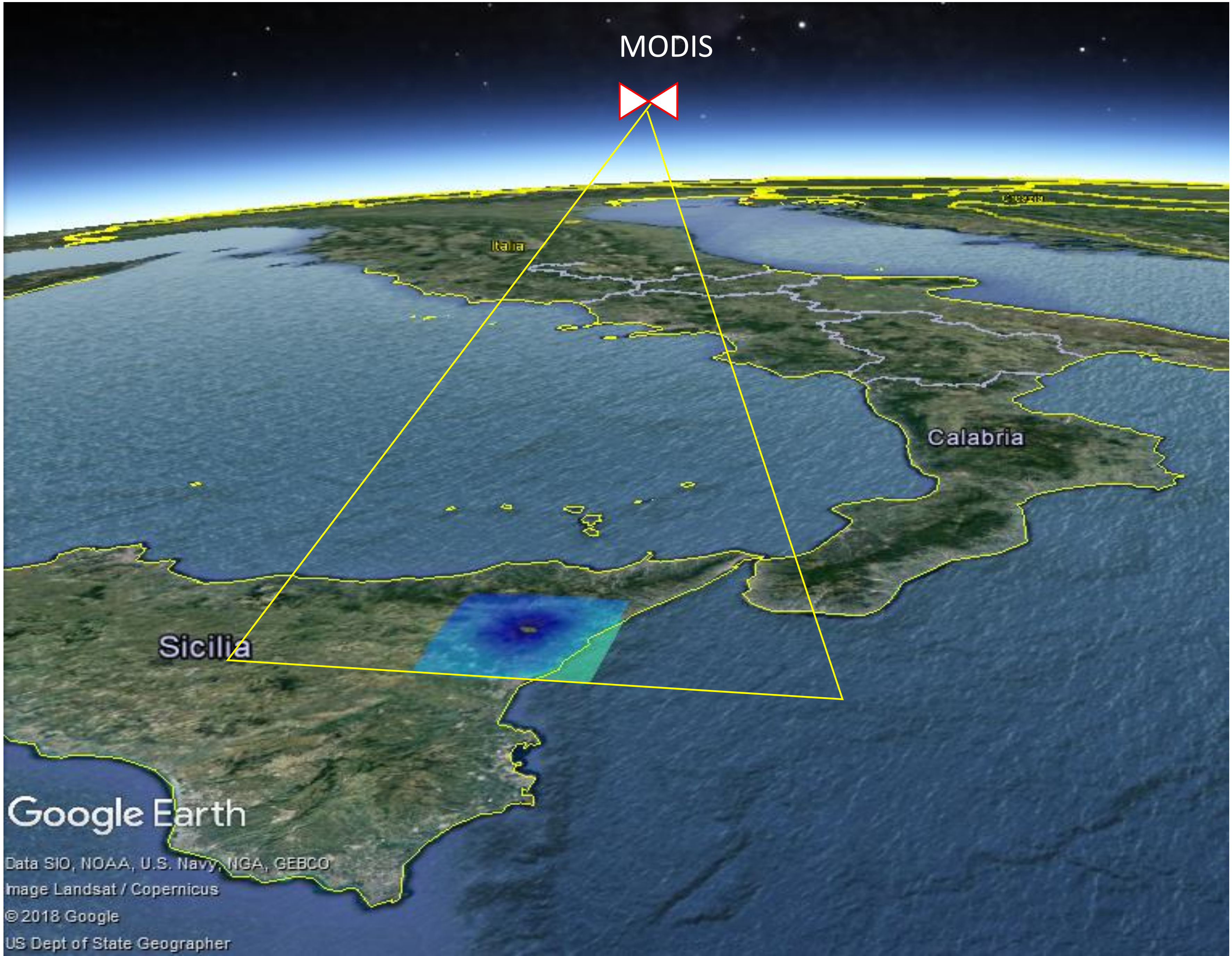
TWO MODIS CARRIED ON TERRA AND AQUA SPACECRAFTS (NASA)

ON ORBIT SINCE 2000 (TERRA) AND 2002 (AQUA)

1 km RESOLUTION IN THE INFRARED BANDS

~ 4 IMAGES PER DAY (2 NIGHT, 2 DAY)

LOW GAIN MIR CHANNEL (~3.96 μm)



MIROVA

INPUT: MODIS NRT DATA

CROP & RESAMPLING: 50 X 50 KM

HOTSPOT DETECTION

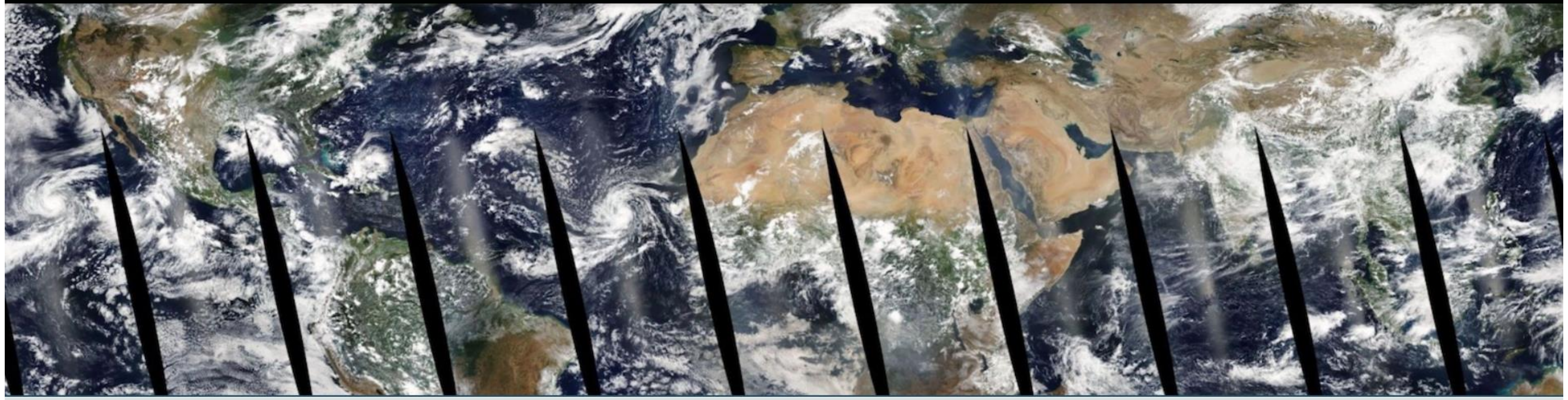
VRP CALCULATION

OUTPUT: VRP Timeseries & Images @ target volcanoes

https://lance-modis.eosdis.nasa.gov/

LANCE-MODIS AND VIIRS-LAND NEAR REAL-TIME DATA

About News Data



Earth Observation Data › LANCE: NASA Near Real-Time Data and Imagery › **LANCE-MODIS Collections 6 & 6.1, VIIRS-LAND Collection 1 & 2**

Data available in 1- 4 hours

Product Name	Download (register for access)	Volume GB/day	PGE	Latency (h:mm) min / avg / max	DOI
Extrapolated Orbital Data	AM1EPHNE	0.000012	97	- / - / -	AM1EPHNE.NRT.061
L0 PDS Data, 5-Min Swath	MOD00F	68.91	95	0.29 / 0.76 / 1.36	MOD00F.NRT.061
L1A Raw Radiances, 5-Min Swath	MOD01	107.35	01	0.45 / 0.93 / 1.52	MOD01.NRT.061
Geolocation, 5-Min Swath 1km	MOD03	8.28	01	0.45 / 0.93 / 1.52	MOD03.NRT.061
L1B Calibrated Radiances, 5-Min Swath 1km L1B Radiances	MOD021KM	31.09	02	0.57 / 1.07 / 1.64	MOD021KM.NRT.061
L1B Calibrated Radiances, 5-Min Swath 500m L1B Radiances	MOD02HKM	20.54	02	0.68 / 1.11 / 1.56	MOD02HKM.NRT.061
L1B Calibrated Radiances, 5-Min Swath 250m L1B Radiances	MOD02QKM	21.95	02	0.68 / 1.11 / 1.56	MOD02QKM.NRT.061

MIROVA

INPUT:
MODIS NRT DATA

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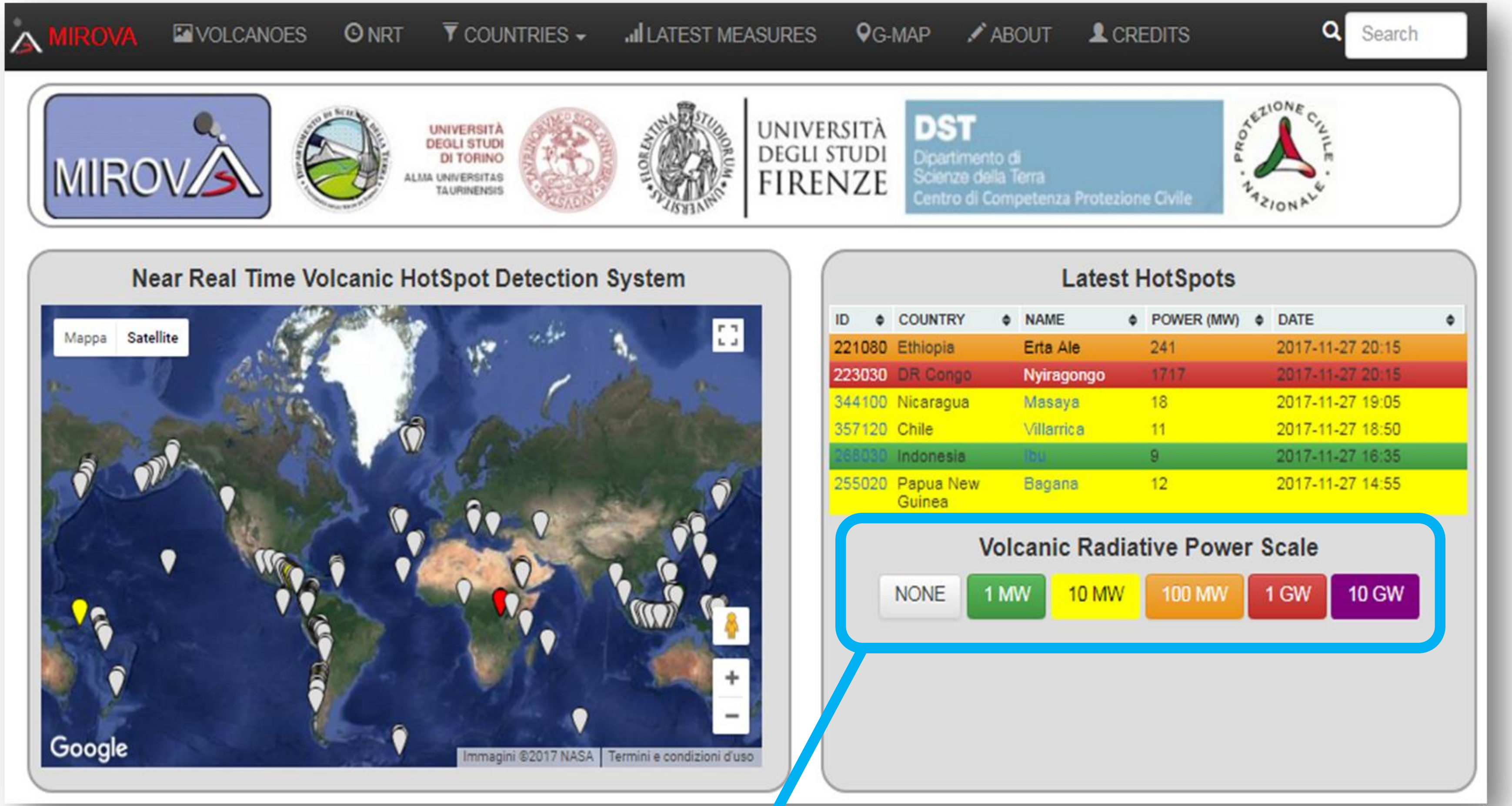
50 X 50 KM

HOTSPOT DETECTION

VRP CALCULATION

OUTPUT:
VRP Timeseries & Images
@ target volcanoes

www.mirovaweb.it



Fully automated: provides data and images within 1 to 4 hours from the satellite overpass (from LANCE)

Thermal output (in MW) subdivided into 5 distinct levels

From < 1 MW to > 10 GW

MIROVA

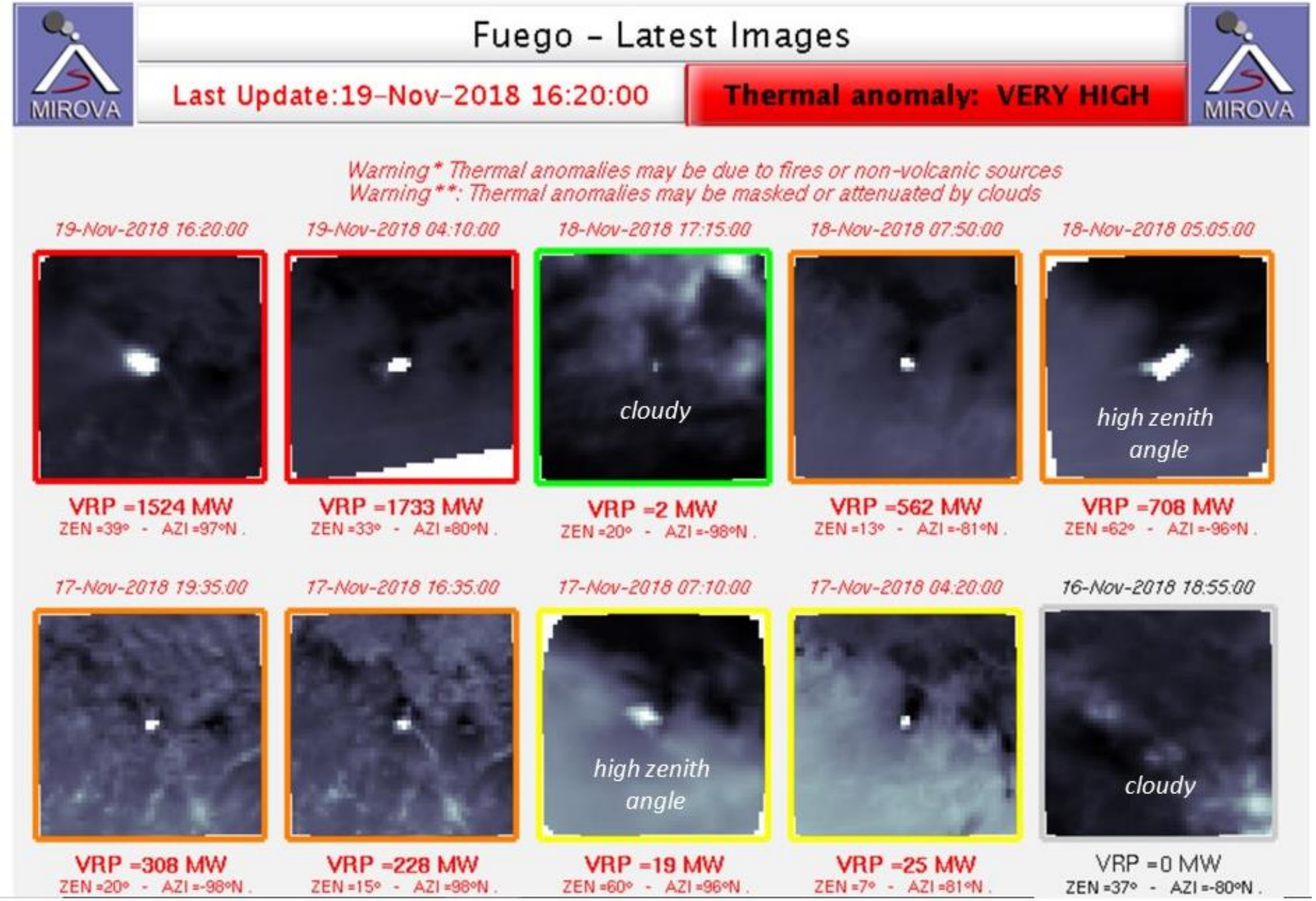
LATEST IMAGES

LOG VRP

DISTANCE

GOOGLE EARTH

SENTINEL 2



Quick overview of the latest thermal images

Daily visualization allows to compile timeseries of VRP of the latest 48 hours as well as to supervise the images

OVERVIEW OF MIROVA | TYPE OF INFORMATION | BEST PRACTICES | APPLICATION CASES

MIROVA

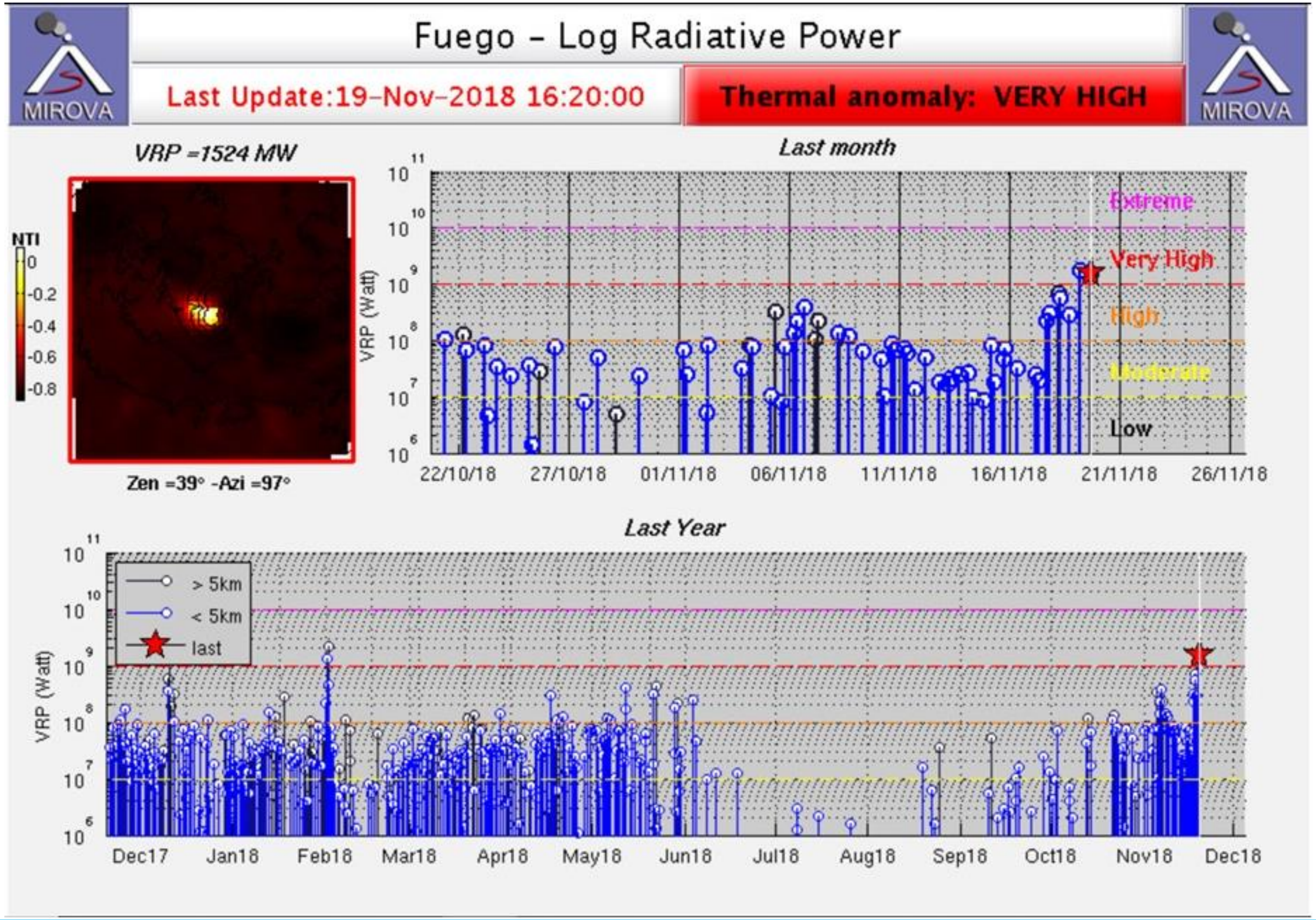
LATEST IMAGES

LOG VRP

DISTANCE

GOOGLE EARTH

SENTINEL 2



Updated VRP time-series in logarithmic scale

Globally the vRP detected by MIROVA spans over more than 5 orders of magnitude. The Log scale allows to visualize this large range of values andtrack major trends and patterns

MIROVA

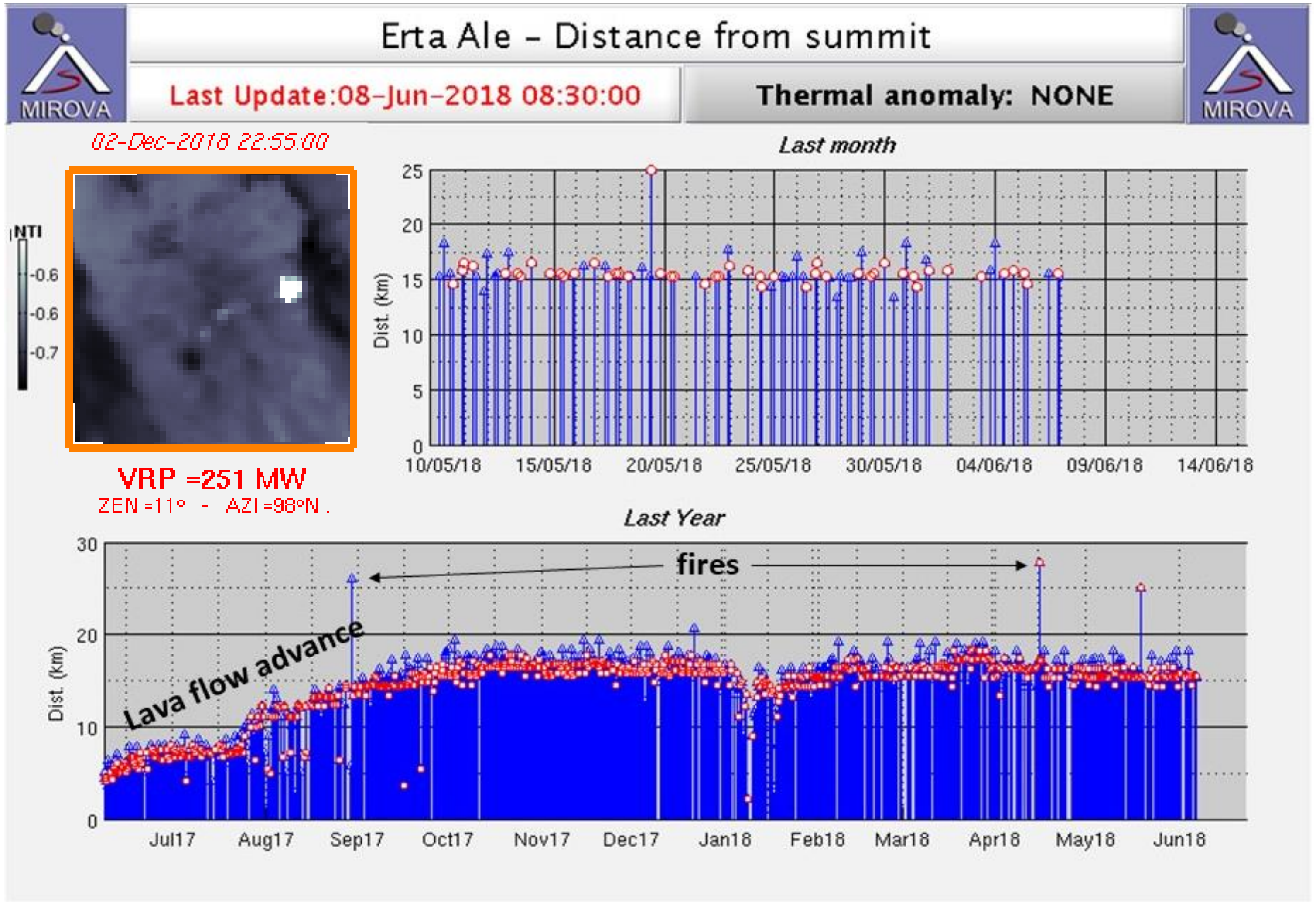
LATEST IMAGES

LOG VRP

DISTANCE

GOOGLE EARTH

SENTINEL 2



Plot of the distance from the summit

Enable to qickly recognize non-volcanic thermal anomalies (e.g. fires) *or track **lava flow advance***

MIROVA

LATEST IMAGES

LOG VRP

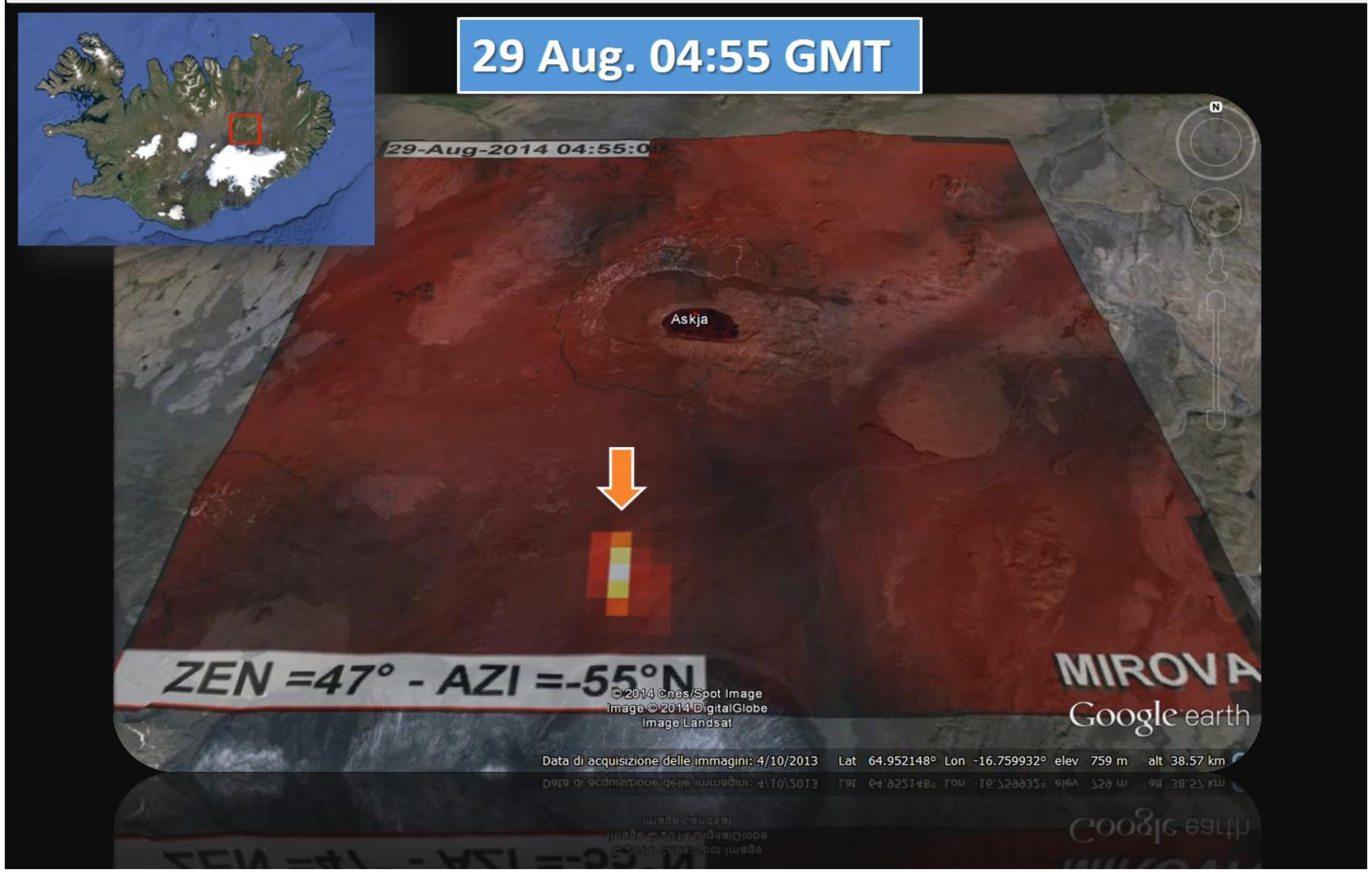
DISTANCE

GOOGLE EARTH

SENTINEL 2

Holuhraun 2014 eruption

First detection



Quick recognition of the location of a thermal anomaly
or track ***lava flow advance***

.kmz file soon available for download

OVERVIEW OF MIROVA | TYPE OF INFORMATION | BEST PRACTICES | APPLICATION CASES

MIROVA

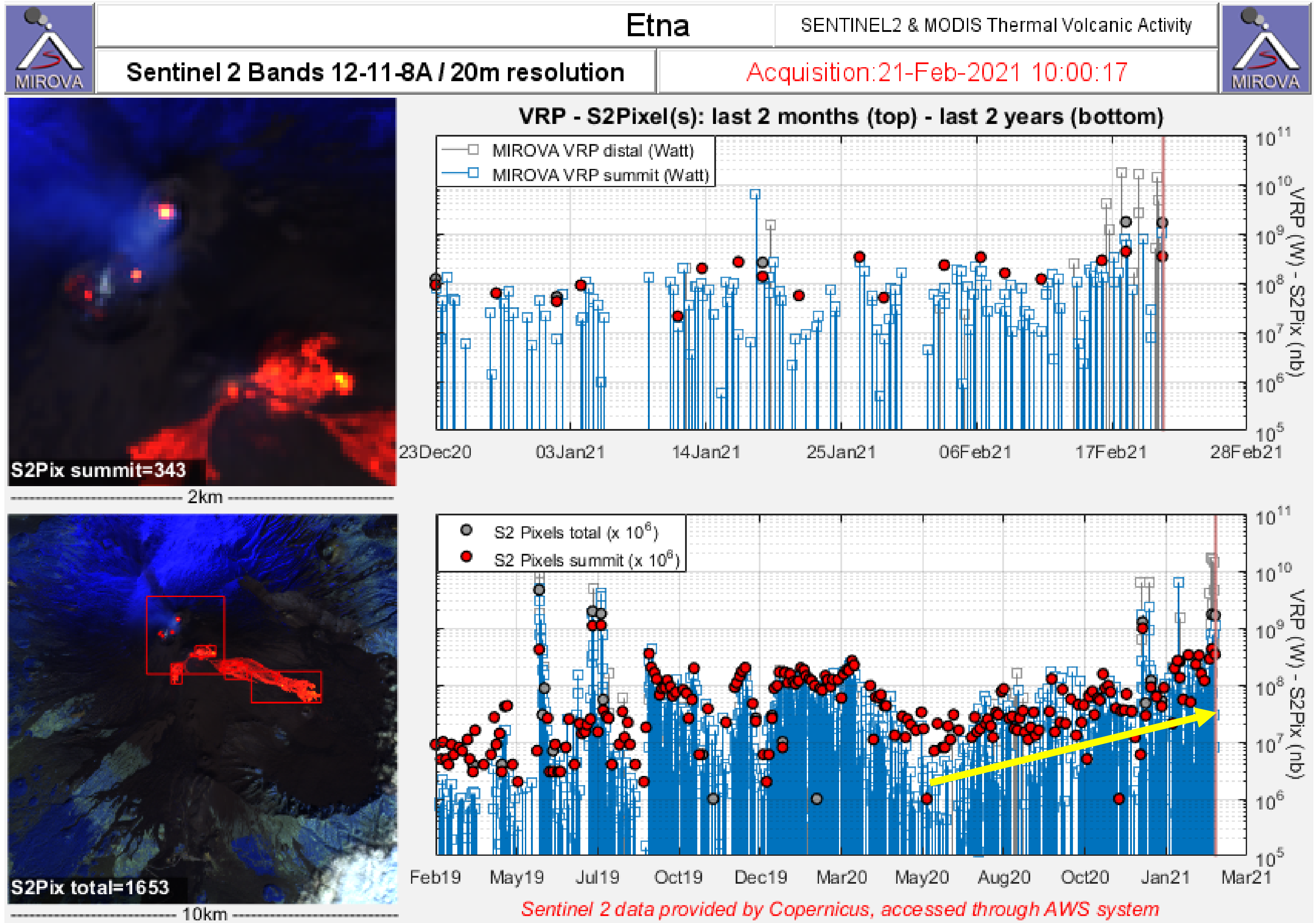
LATEST IMAGES

LOG VRP

DISTANCE

GOOGLE EARTH

SENTINEL 2



NEW!

Number of Hot Pixel detected by Sentinel 2 (*Massimetti et al. 2020*)

Slideshow soon available for visualization

MIROVA

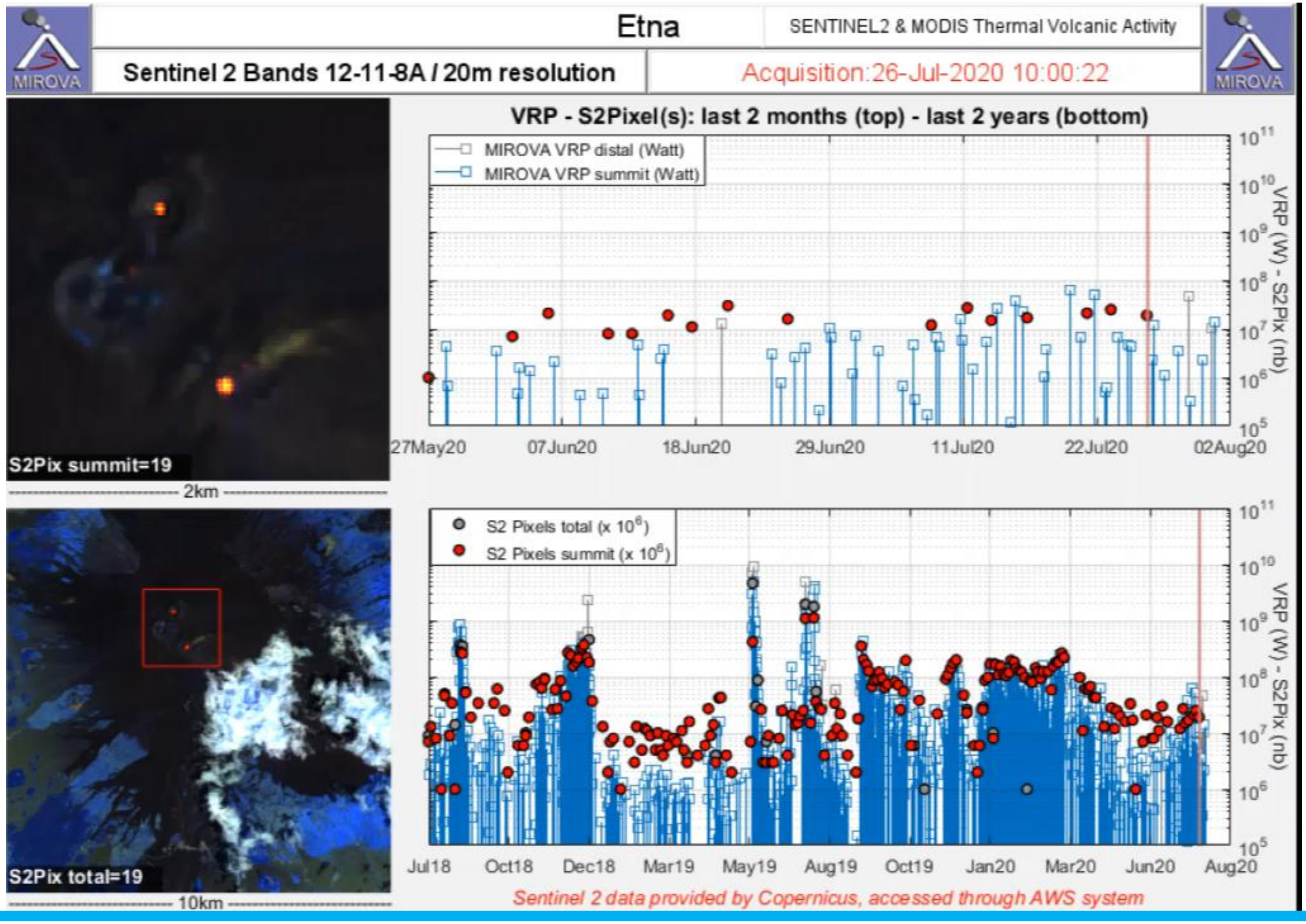
LATEST IMAGES

LOG VRP

DISTANCE

GOOGLE EARTH

SENTINEL 2



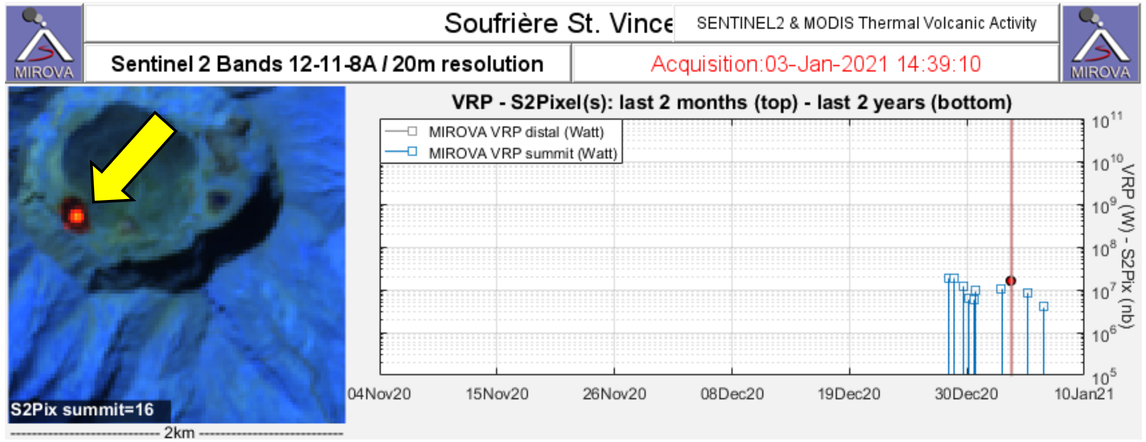
NEW!

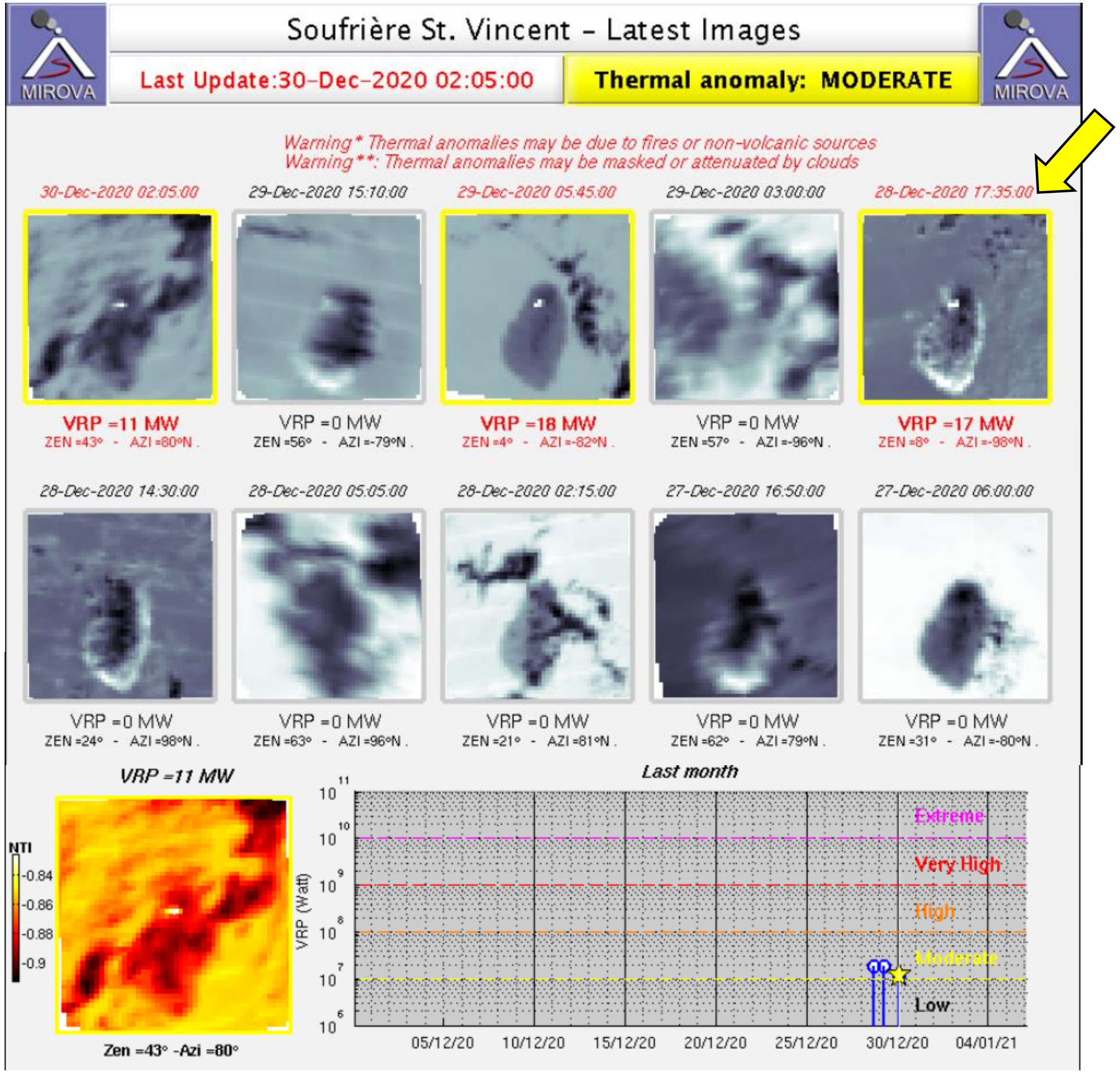
Number of Hot Pixel detected by Sentinel 2 (*Massimetti et al. 2020*)

Slideshow soon available for visualization

What kind of information is retrieved from MIROVA

1. ***Presence or absence of thermal anomalies (timing of an eruption):***
2. *Intensity/Trend of the thermal anomaly*
3. *Location/dimension of the hotspot and its distance from the volcanic summit*





What kind of information is retrieved from MIROVA

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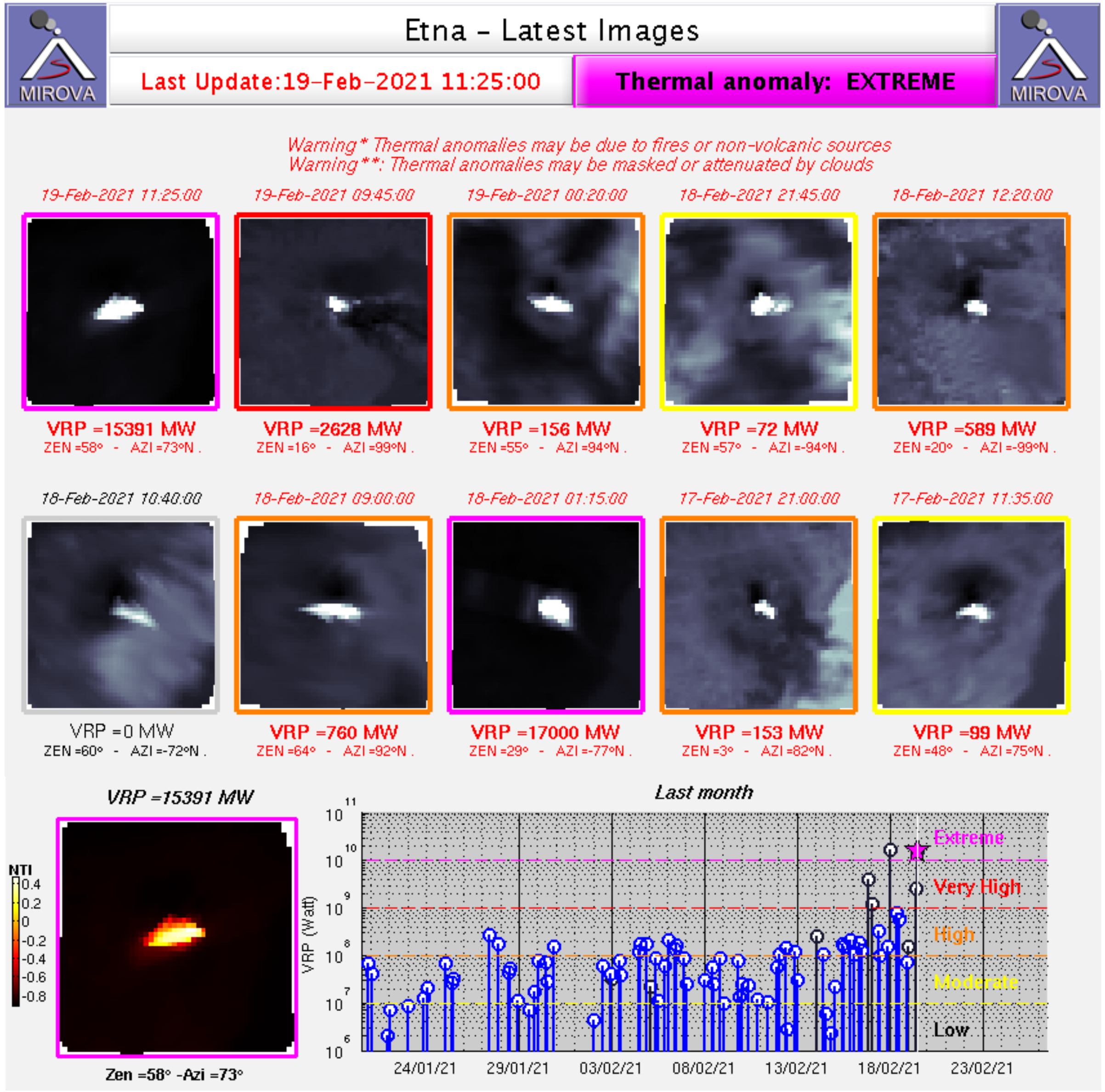
Volcanic Radiative Power Scale

NONE	1 MW	10 MW	100 MW	1 GW	10 GW

i.e. Etna eruption on 19 Feb 2021 11:25 UTC



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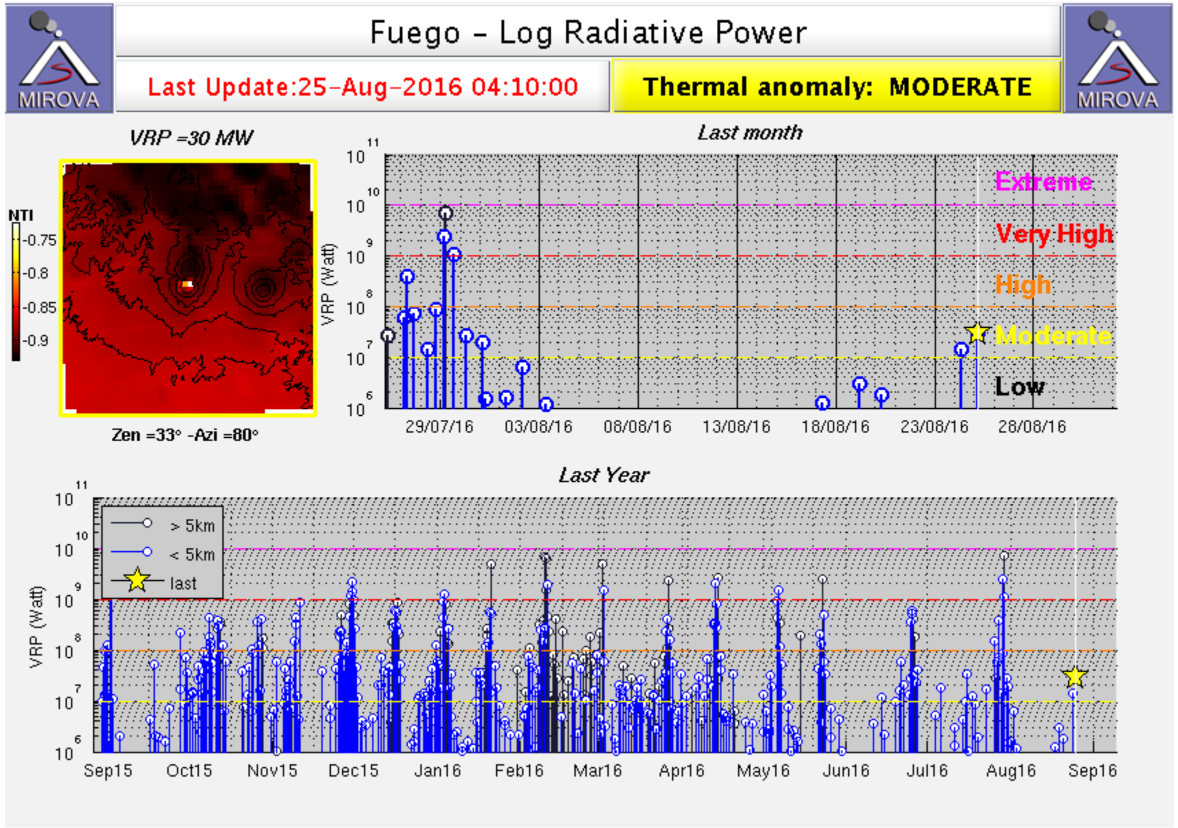
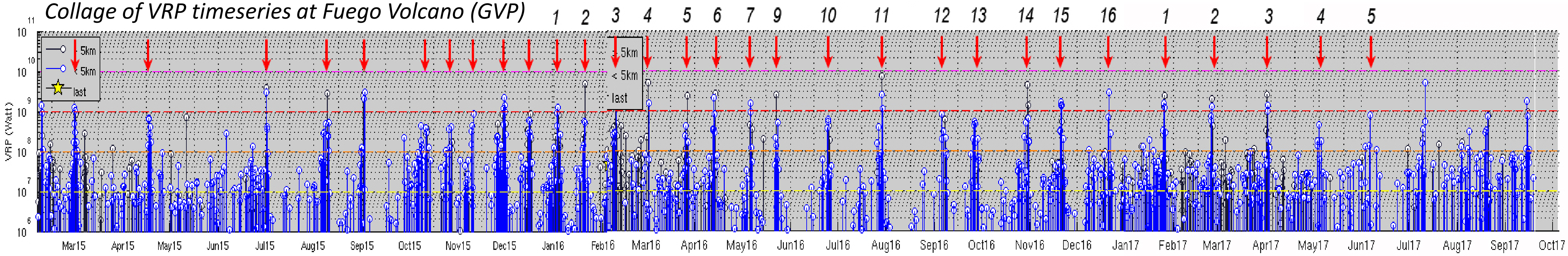
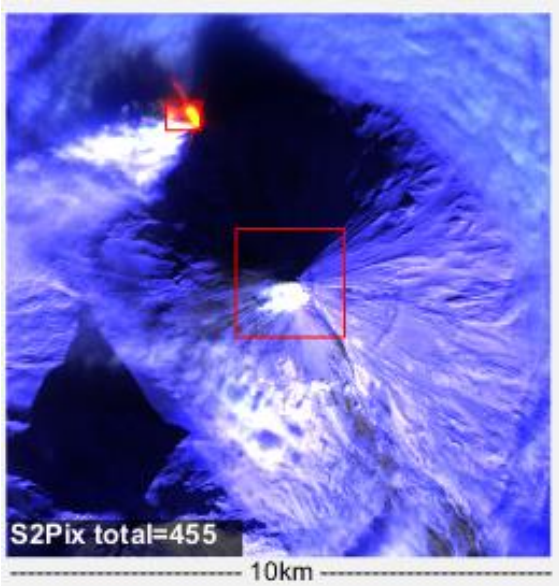


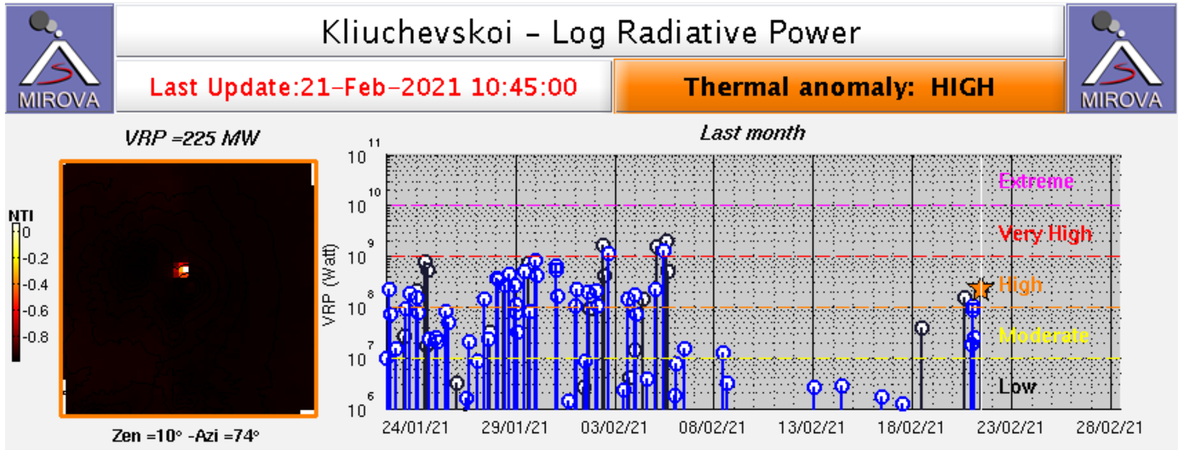


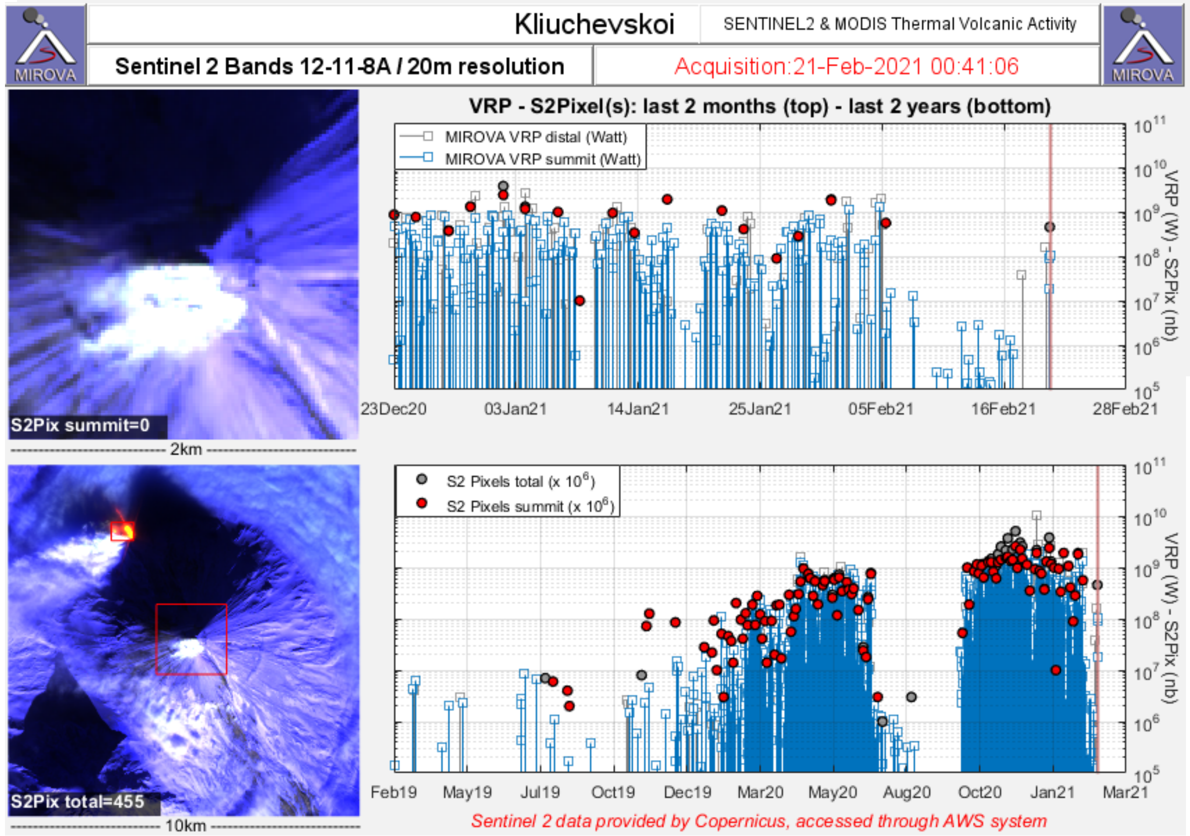
Collage of VRP timeseries at Fuego Volcano (GVP)

What kind of information is retrieved from MIROVA

1. *Presence or absence of thermal anomalies (timing of an eruption):*
2. *Intensity/Trend of the thermal anomaly*
3. ***Location/dimension of the hotspot and its distance from the volcanic summit***



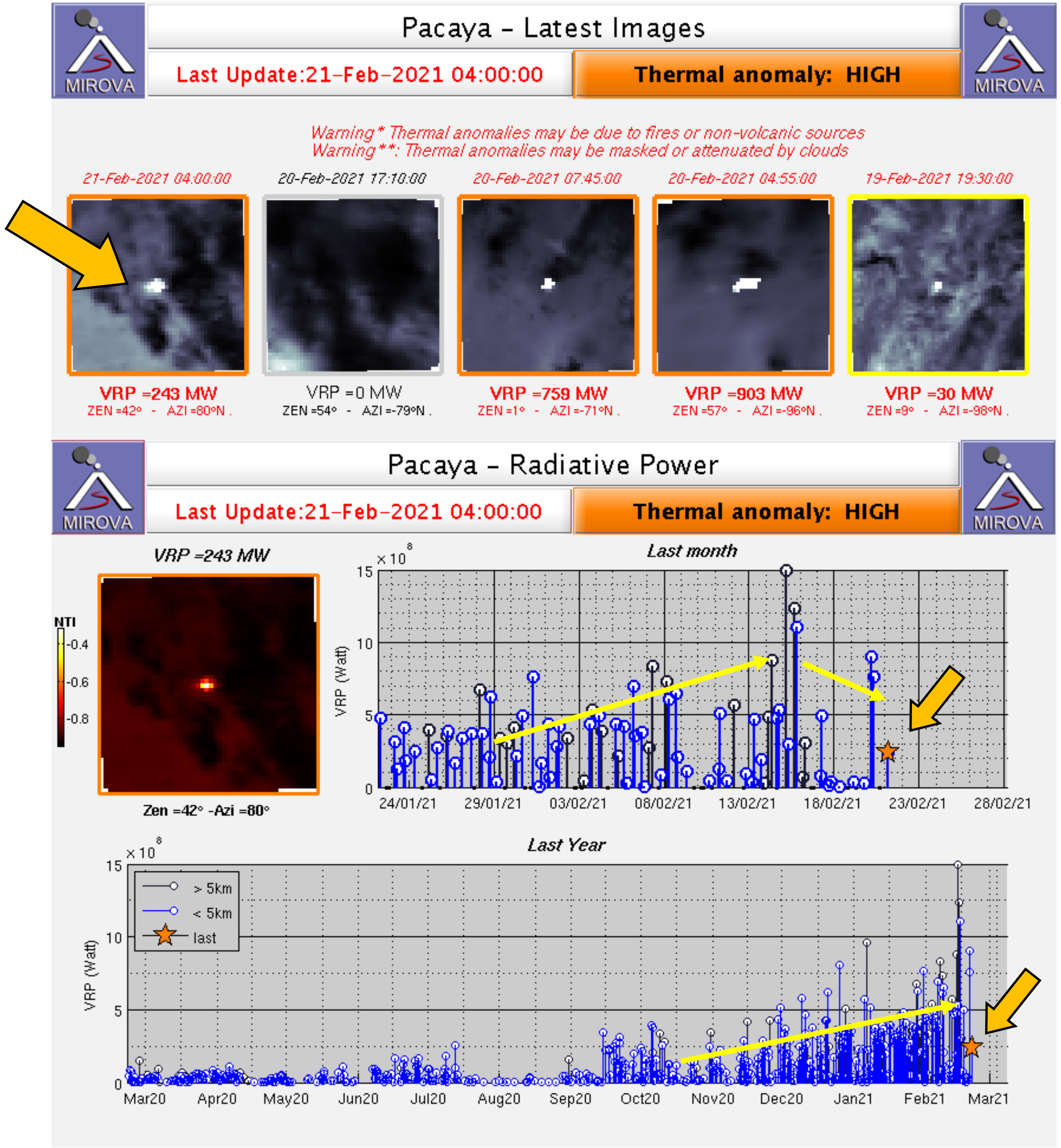




Best Practice 1:
Look at the trends (at different timescales) rather than single data points

In many cases a single data does not give us particular information about the thermal state of a volcano because some volcanic processes occur on timescales of days, months or years.

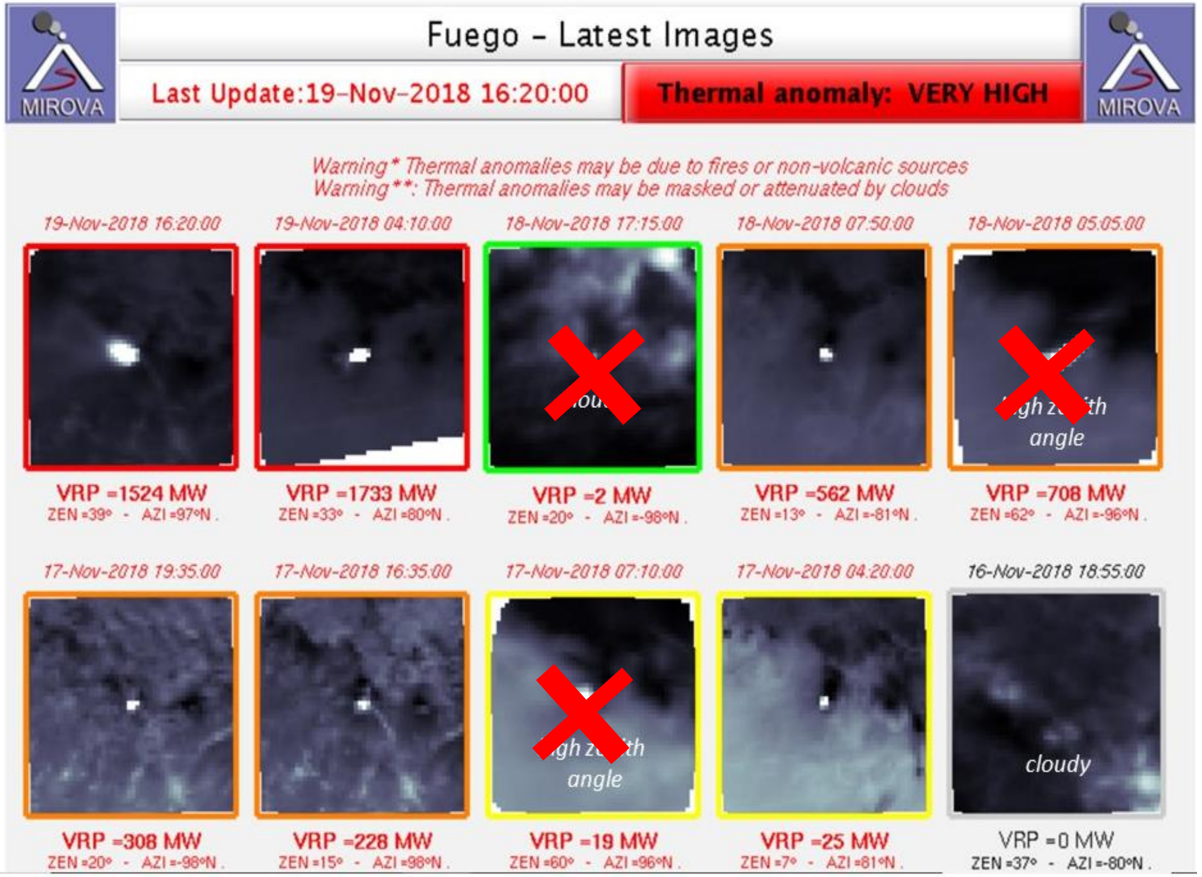
- Take into account the evolution of the data on different time scales (daily, weekly, monthly or yearly).
- Wait further images/data to confirm/validate an eruptive trend/pattern



Best Practice 2:
Look at the images, not only at the associated numbers (VRP)

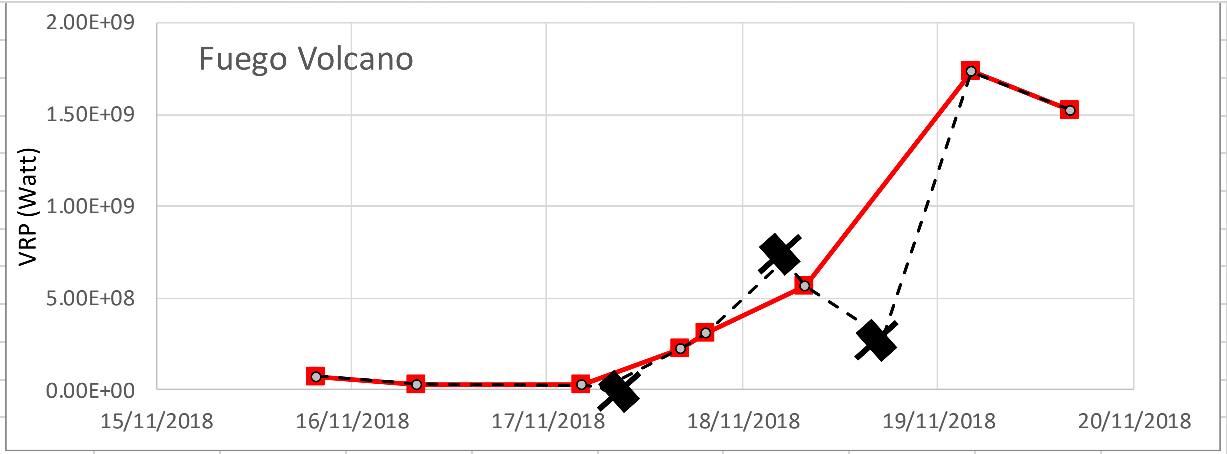
Each single image should be evaluated in order to exclude the effects of:

- *Clouds*
- *Volcanic Plumes*
- *Viewing Geometry*
- *Fires/Antropic*
- *False alerts*



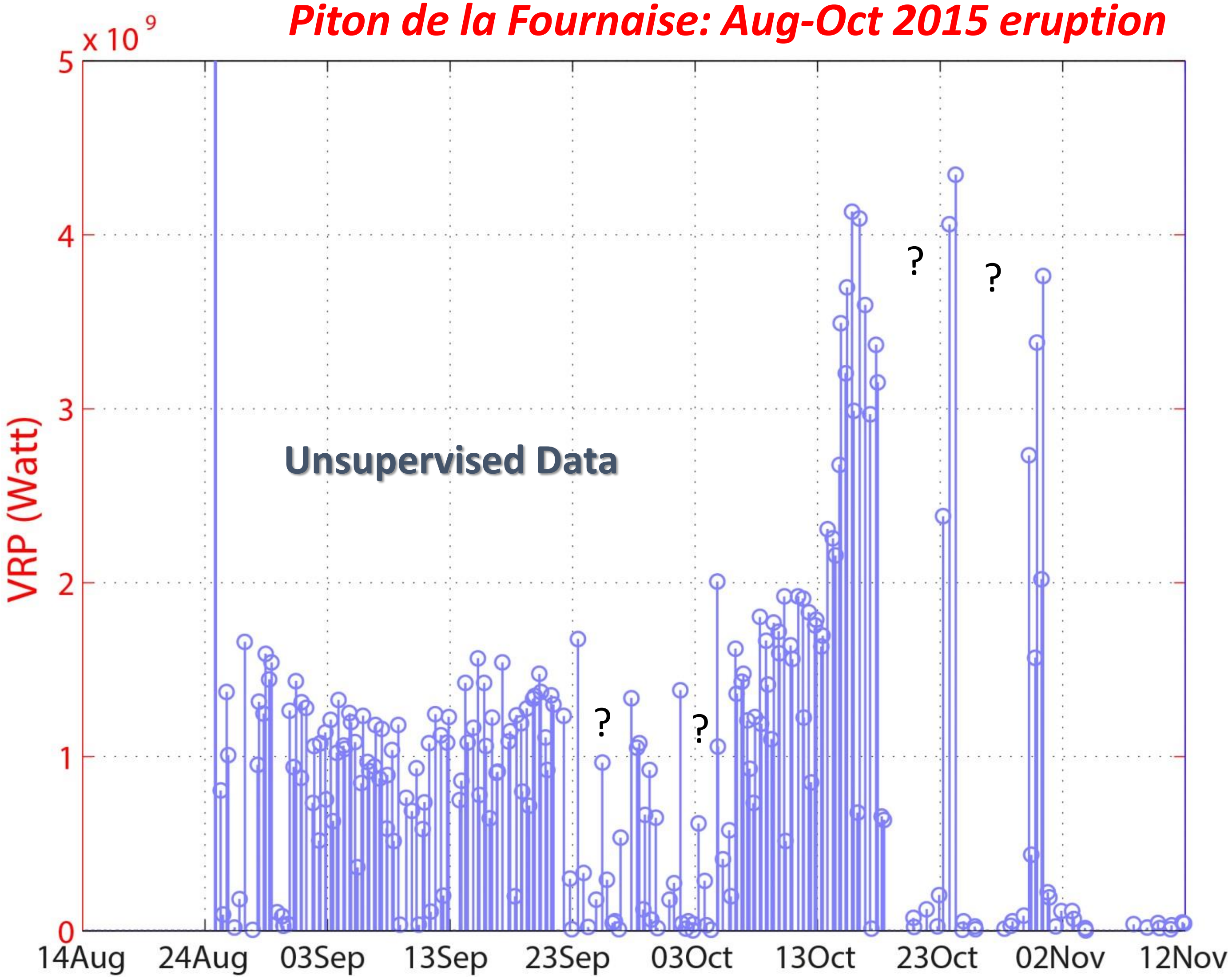
Data excluded

Date	VRP (Watt	sat zen	sat azi	quality
15/11/2018 19:50	7.20E+07	43.04907	-97.4118	1
16/11/2018 08:05	3.17E+07	37.63543	-80.4545	1
17/11/2018 04:20	2.51E+07	7.33894	81.76579	1
17/11/2018 07:10	1.90E+07	60.62727	96.09572	0
17/11/2018 16:35	2.29E+08	15.23142	98.59837	1
17/11/2018 19:35	3.09E+08	20.99652	-98.1587	1
18/11/2018 05:05	7.09E+08	62.76371	-96.3102	0
18/11/2018 07:50	5.62E+08	13.46179	-81.5903	1
18/11/2018 17:15	2.92E+08	59.7177	-79.0103	0
19/11/2018 04:10	1.73E+09	33.32163	80.67129	1
19/11/2018 16:20	1.52E+09	39.09105	97.42218	1



Best Practice 3:
Supervise the data to detect true changes in heat flux due to volcanic activity

Piton de la Fournaise: Aug-Oct 2015 eruption



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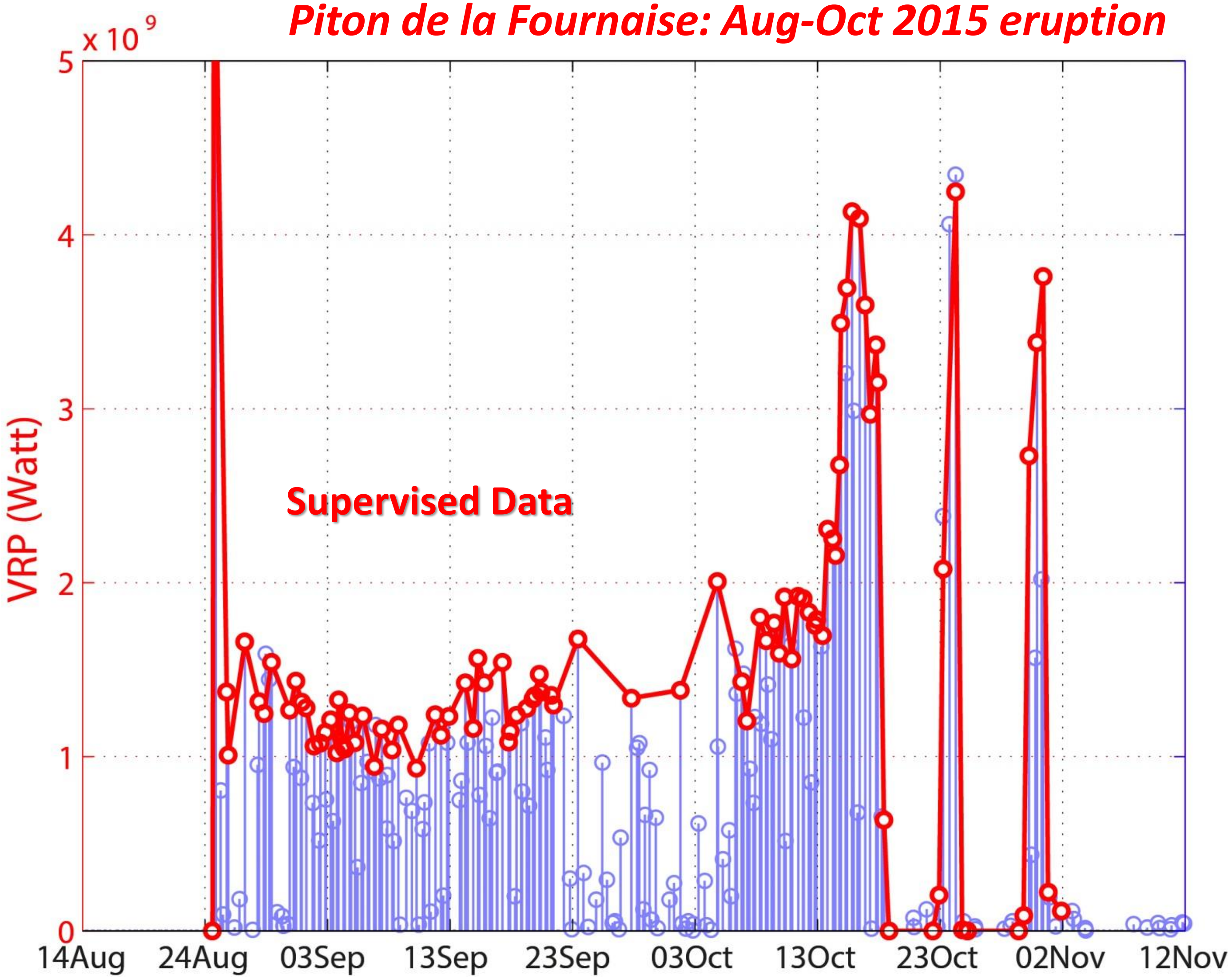
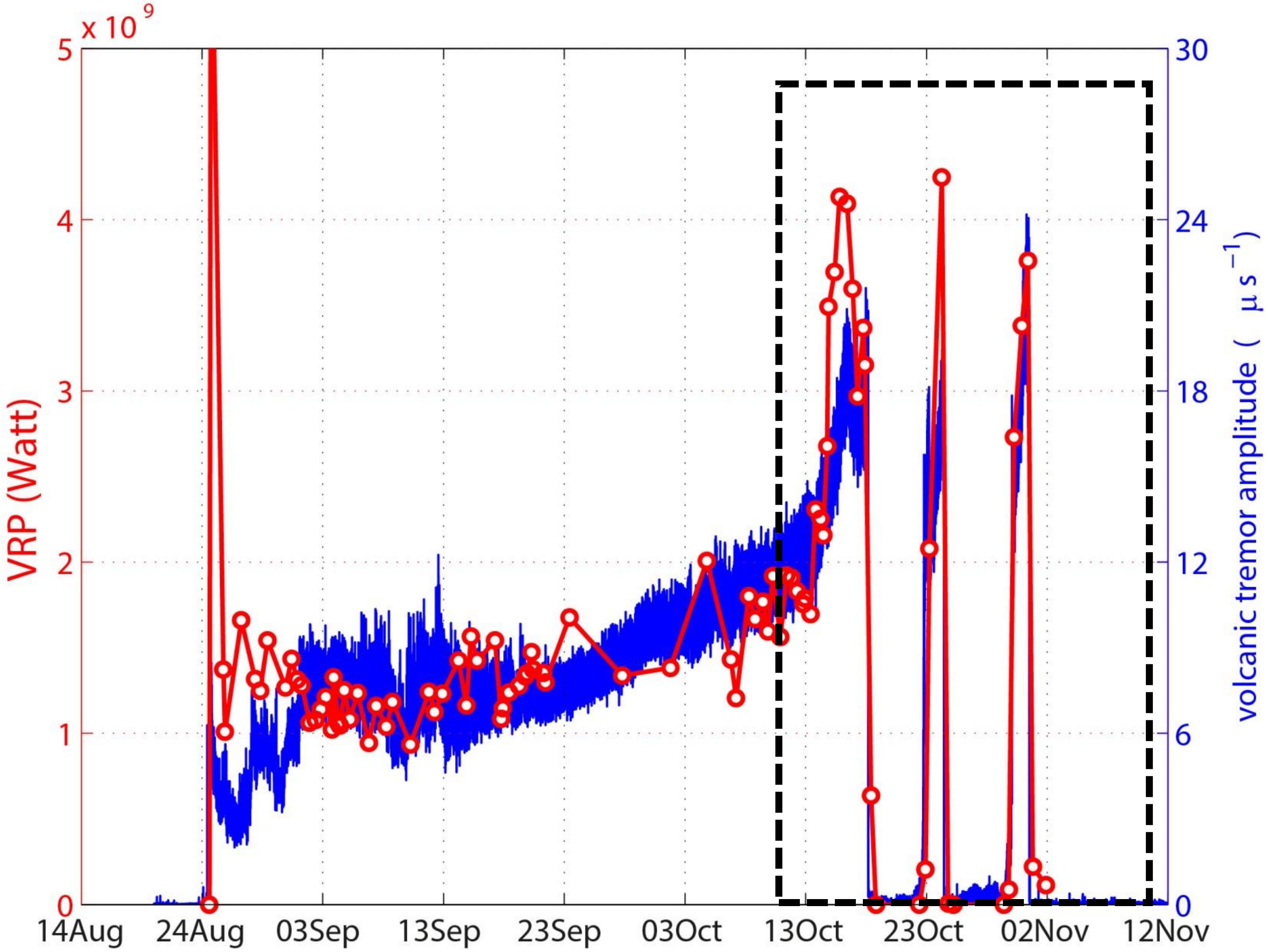
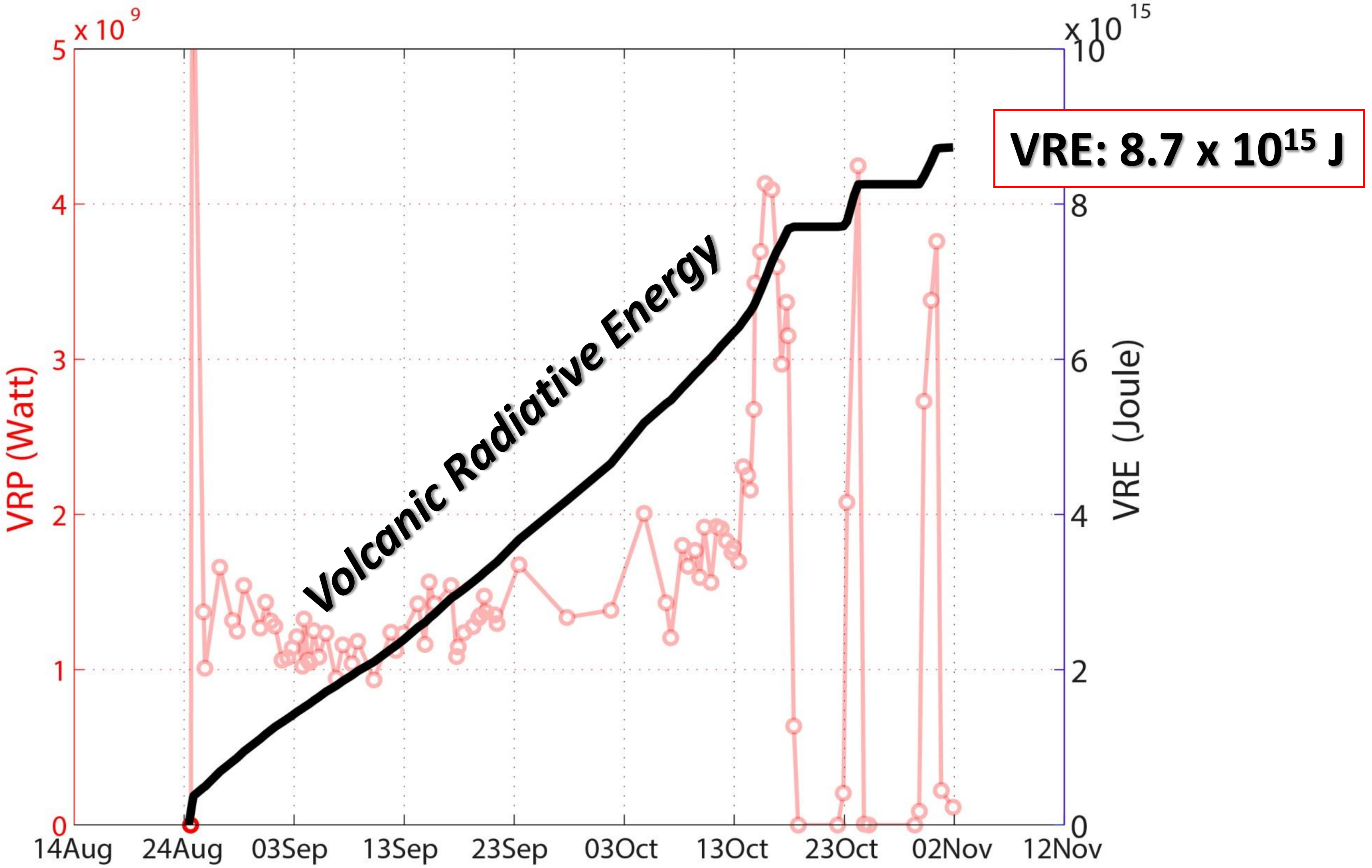


Best Practice 4:
Compare VRP data with other parameters (seismicity/degassing/deformation)



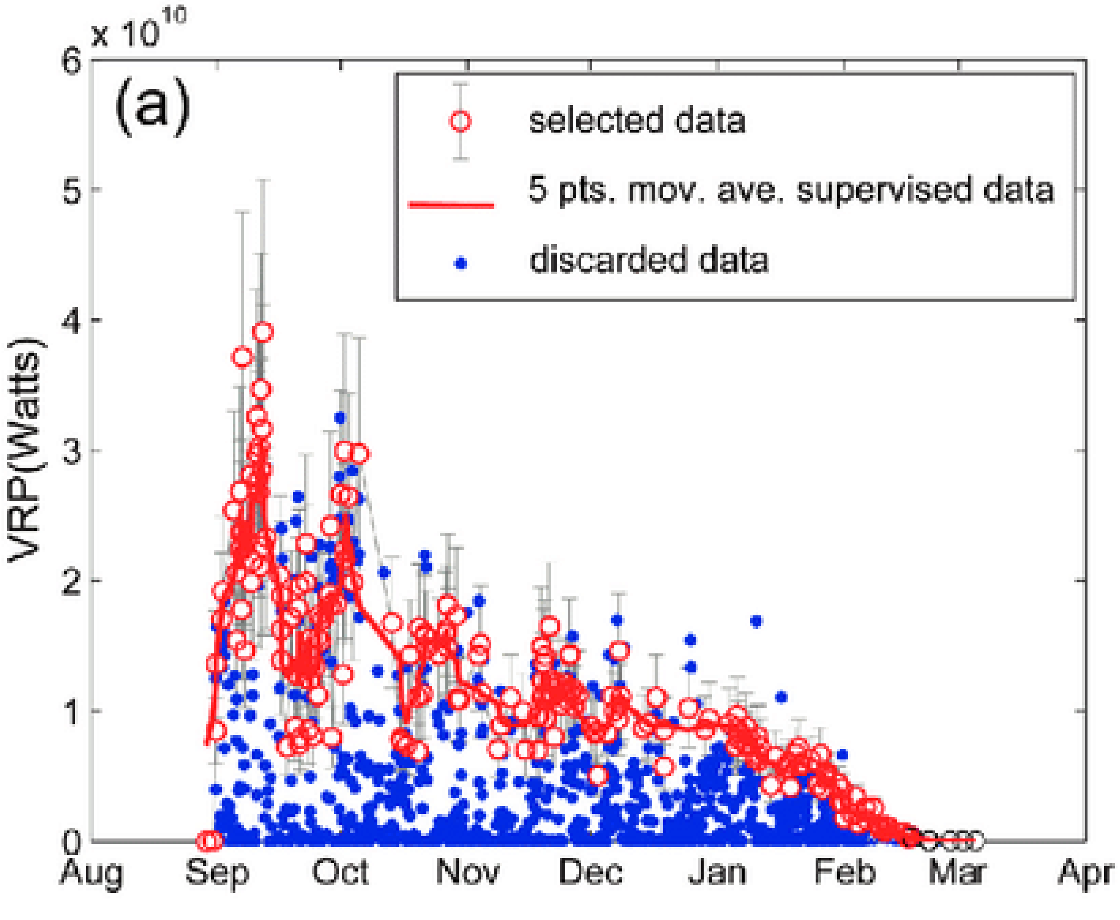
Seismic data courtesy of V. Ferrazzini and OVPF

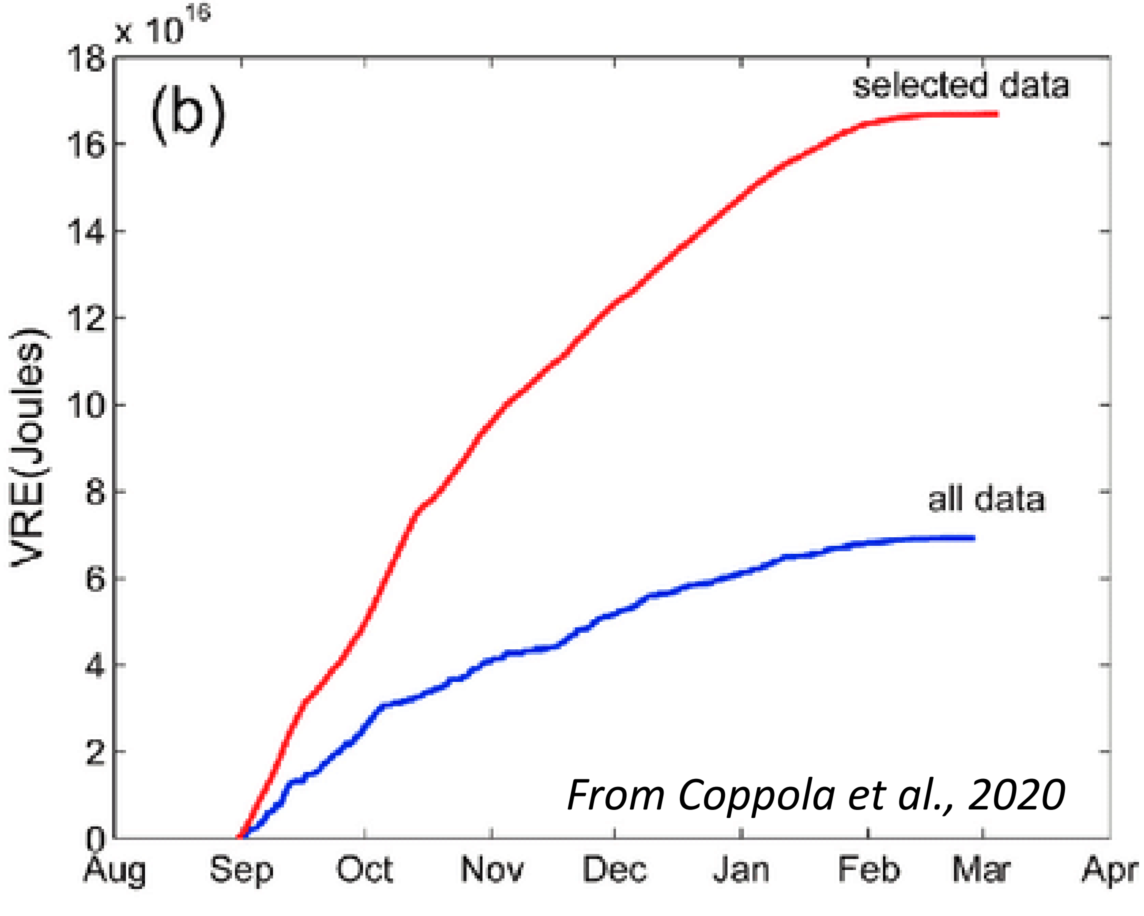
Best Practice 5:
Integrate the VRP to obtain the total energy radiated (VRE). Some pattern may become more evident



Best Practice 6:
If supervised data are not availbale, the total energy calculated from all the data will be underestimated!
…….. But the overall trend is still good!

Holuhraun 2014-2015 eruption





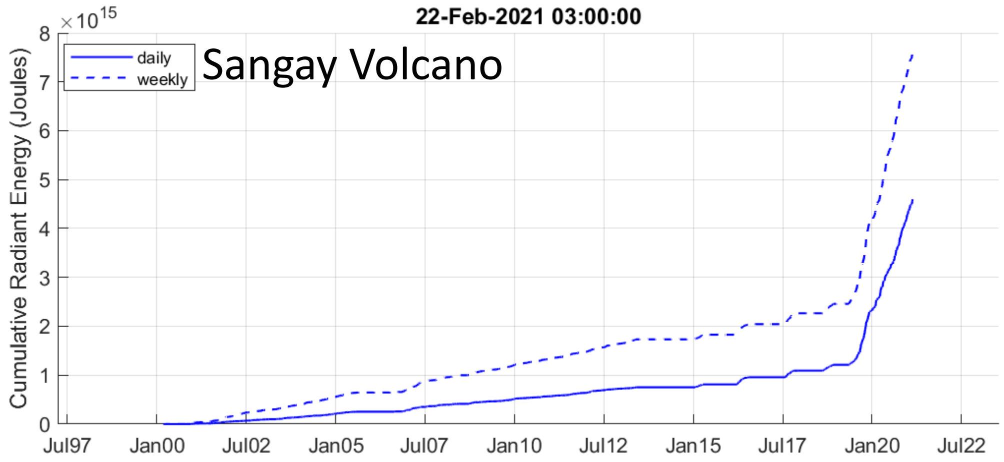
Best Practice 7:
A convenient way to calculate VRE without data supervision

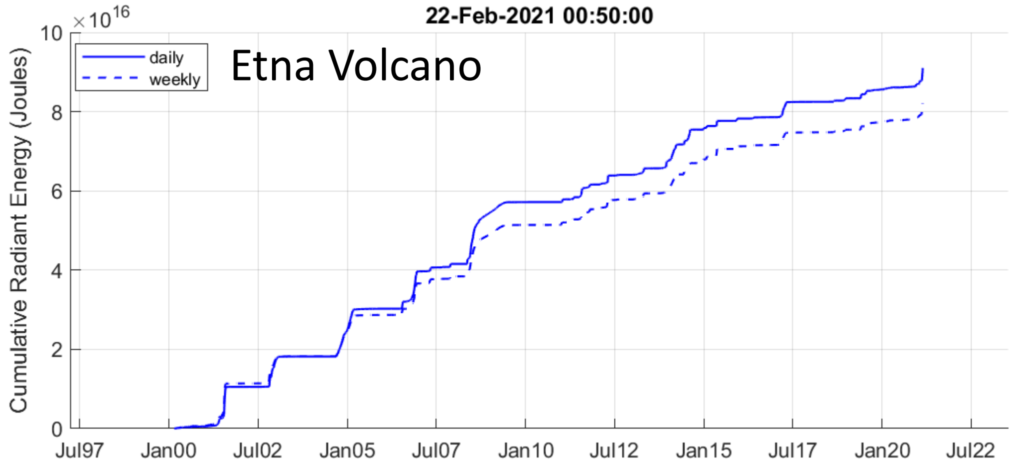
In many case is not possible/convenient to supervise the whole dataset (tens of thousands of images).

It is therefore practical to calculate the VRE as:

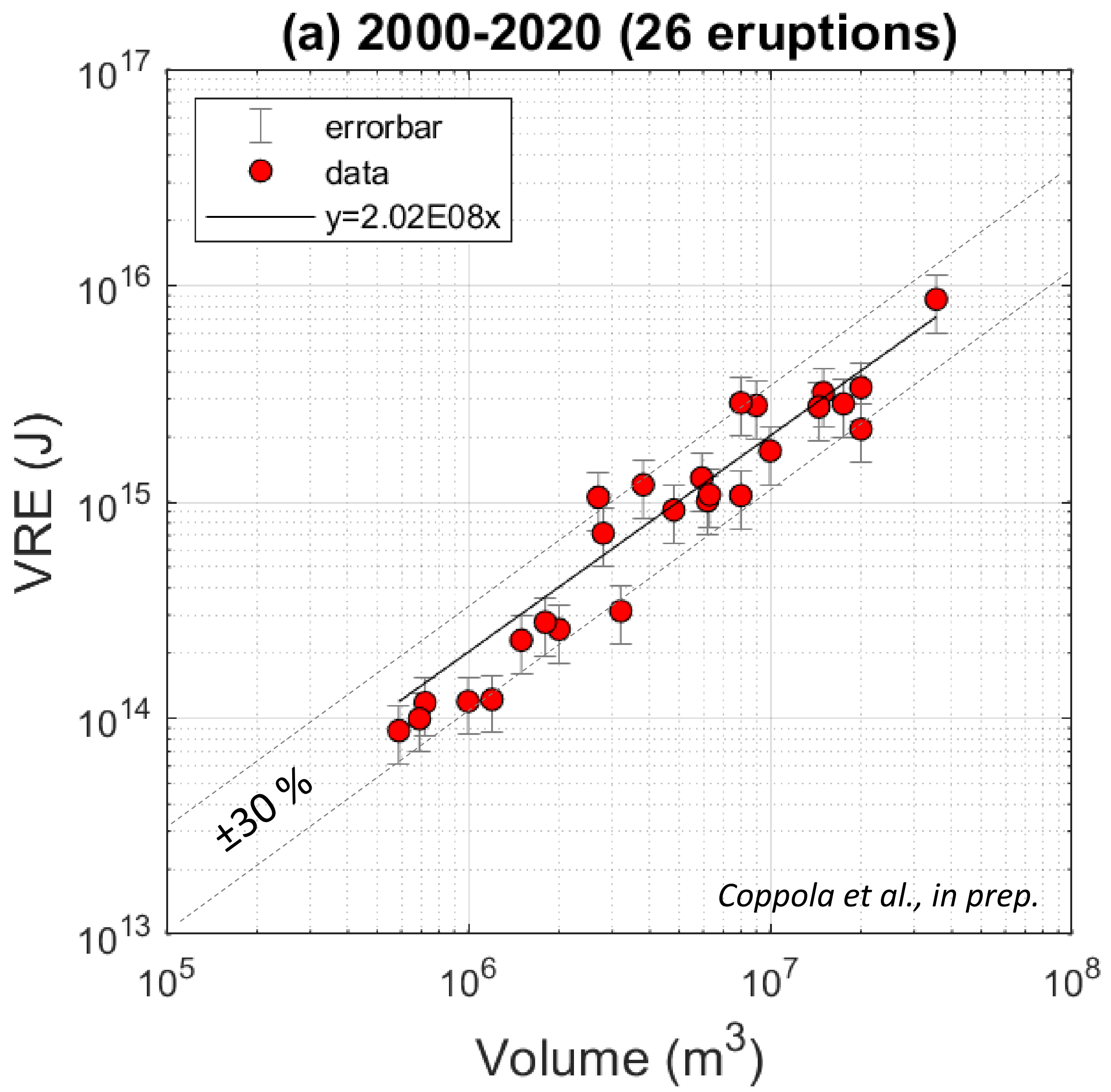
- Calculate the **maximum daily VRP** and integrate it over time windows of 24 hours;
  this method is more effective during a continuous effusive activity in which we have practically continuous thermal anomalies

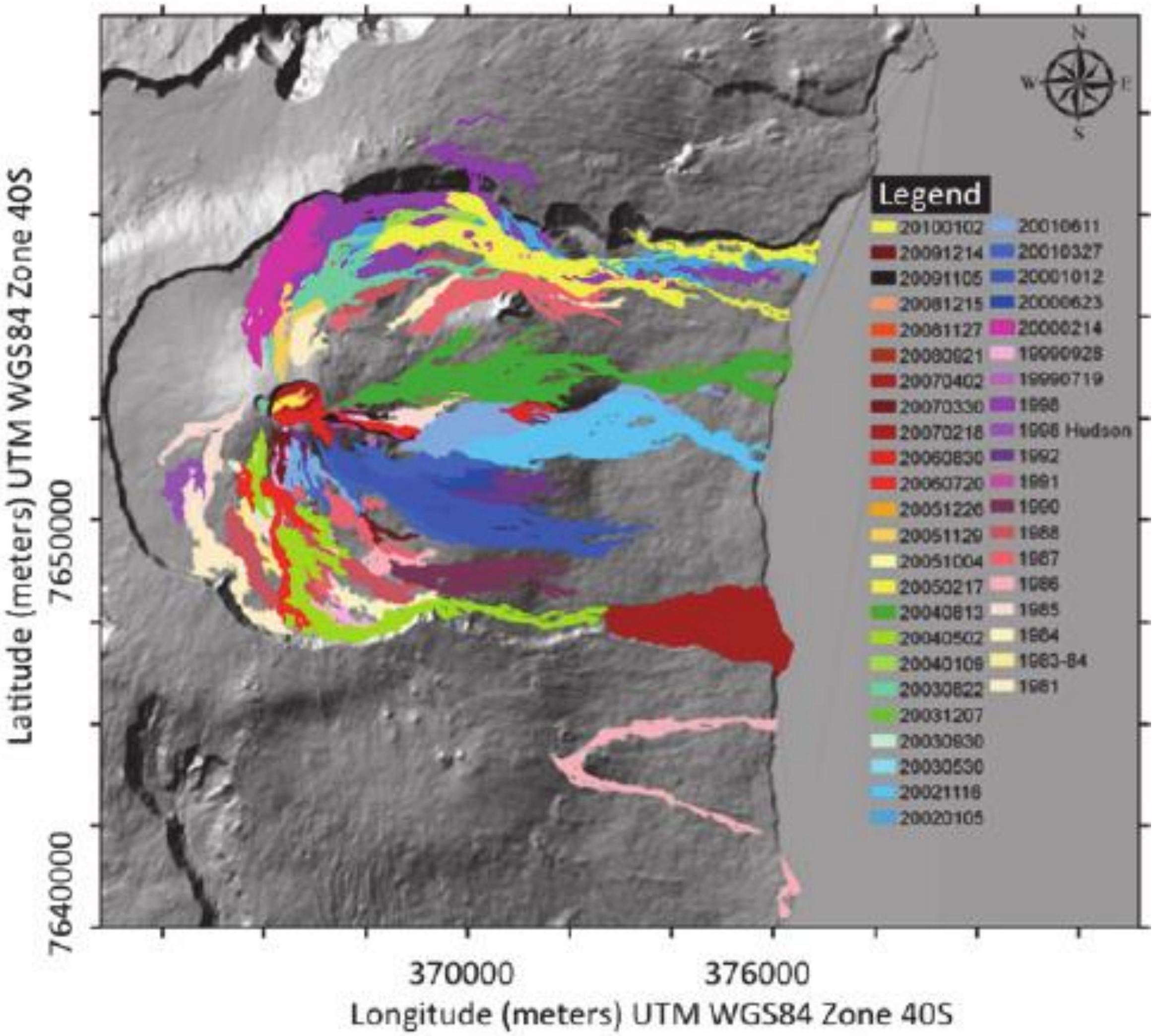
- Calculate the **mean weekly VRP** and integrate it over time windows of 7 days;
  this method is most effective during periods of low activity in which several days can pass between one anomaly and the next





During effusive eruption the VRE is correlated to erupted lava volume. For a single volcano the correlation depends mainly on local factors such as topography and cooling rate

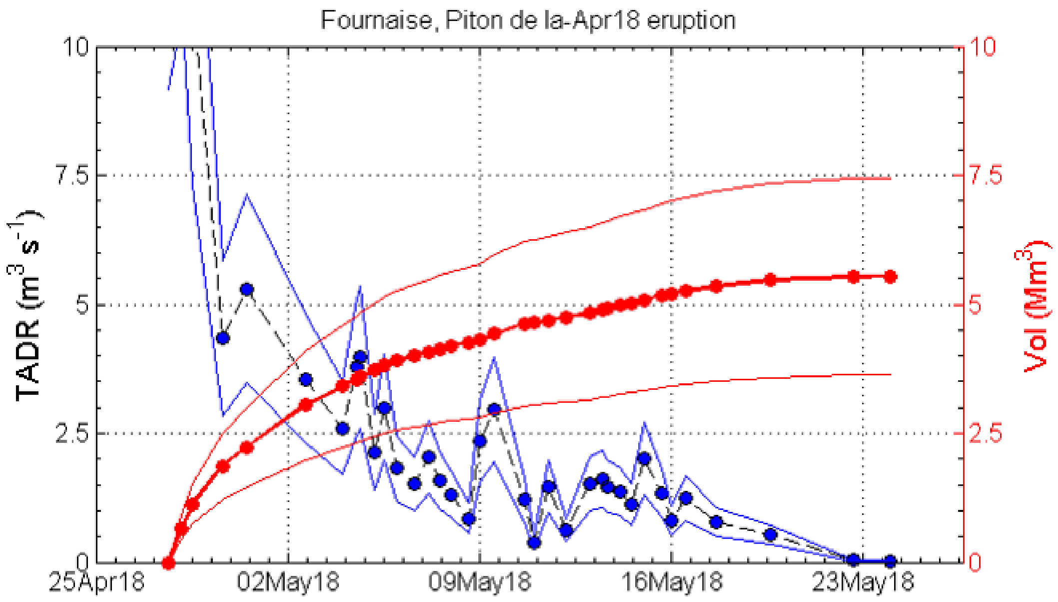




INTEGRATED SATELLITE-DATA-DRIVE RESPONSE TO EFFUSIVE CRISIS AT PITON DE LA FOURNAISE

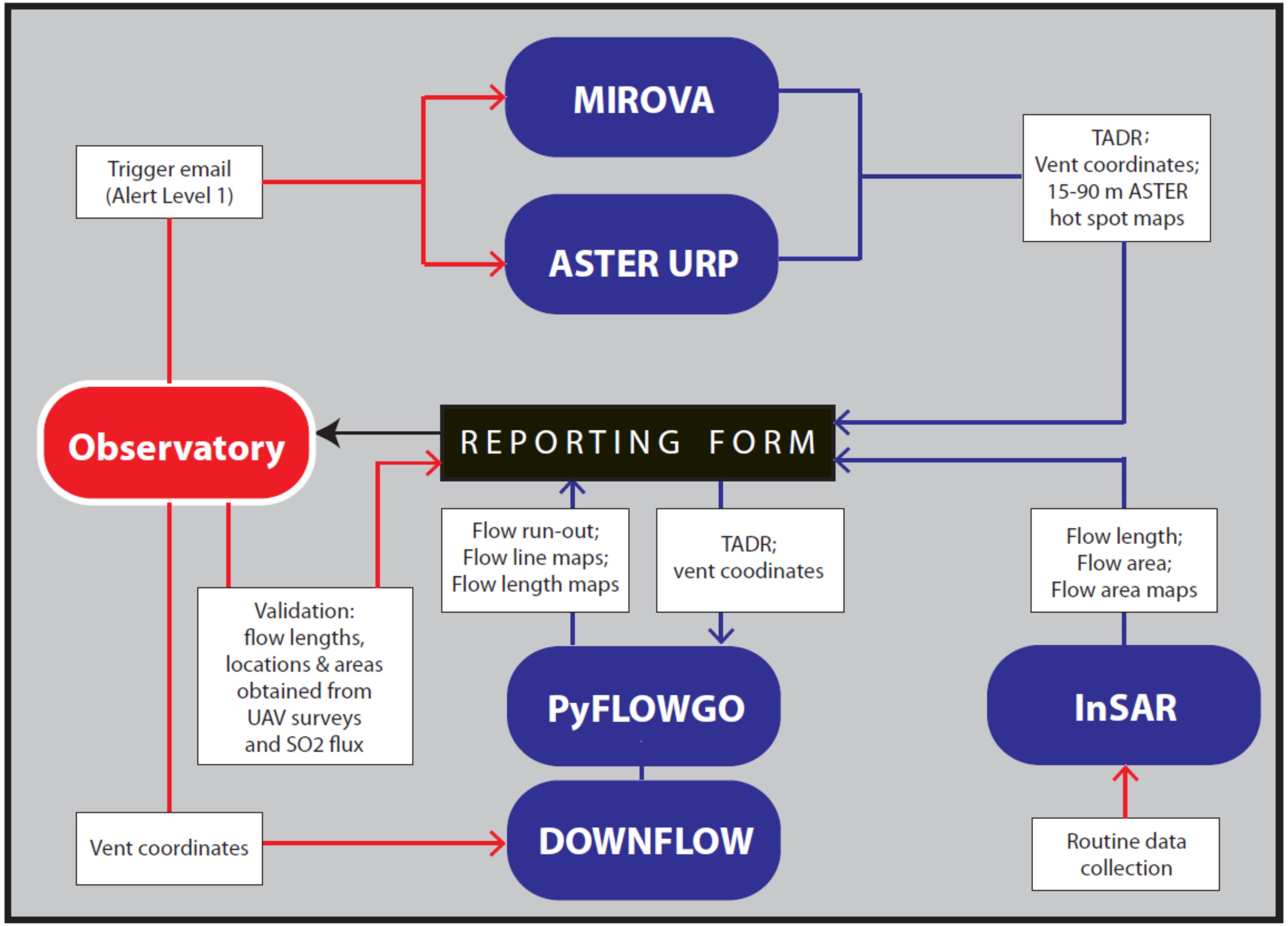
LAVA FLOW FIELD REPORTING FORM (file name save format: yyyymmdd-Volcano name-ANR-LAVA-REPORT-##)			
Target		Piton de la Fournaise	
Eruption Start Date and Time (local)		2018-04-27-T-23:50 (local time)	
Report Date and Time (UTC)		2018-04-28-T-09:00 (GMT)	
Up-dated by		HARRIS Andrew	
Field 1: TIME-AVERAGED DISCHARGE RATE			
Sensor		MODIS	
Processing System		MIROVA	
Last update		2018-05-24T06:10:00	
Up-dated by		COPPOLA Diego	
Image Date	Image Time	TADR-min	TADR-max
15-05-2018	06:15:00	1,32	2,71
15-05-2018	21:30:00	0,88	1,81
15-05-2018	21:30:00	0,88	1,81
16-05-2018	06:55:00	0,53	1,09
16-05-2018	19:05:00	0,82	1,69
16-05-2018	19:05:00	0,82	1,69
17-05-2018	21:20:00	0,51	1,05
19-05-2018	21:05:00	0,35	0,73
22-05-2018	21:35:00	0,02	0,04
24-05-2018	06:10:00	0,02	0,03

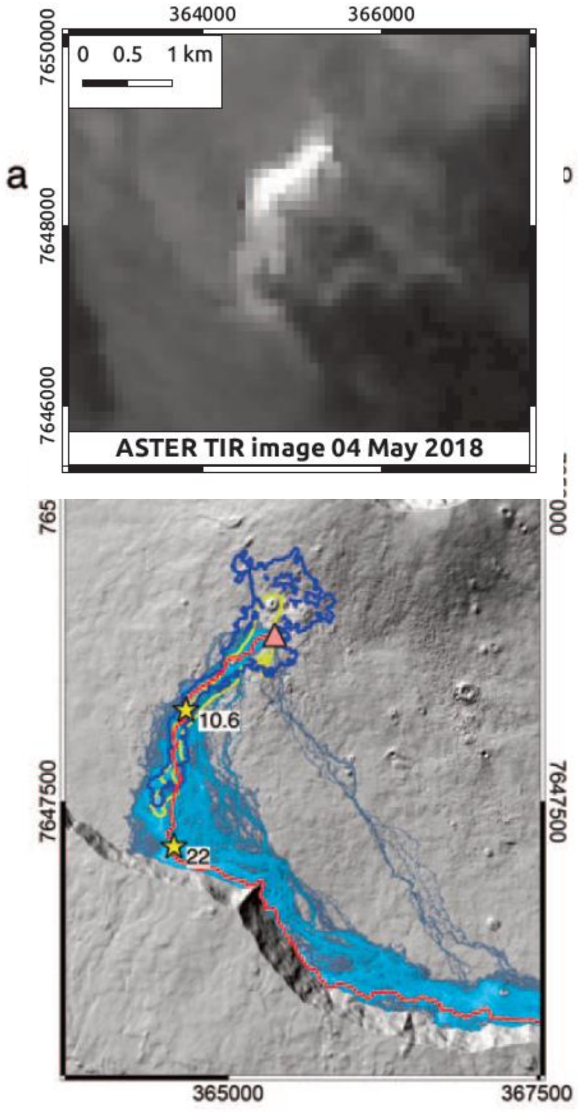
Time Series:			
Start date	Current date	No. data points	Duration
2018-04-27T21:45	2018-05-24T06:10	35	27



Comments:
The MODIS image acquired today at 06:10 UTC, indicates very low thermal activity over the lava field (~5 MW) corresponding to a very low TADR (0.015 to 0.03 m3/s). However, this low thermal flux could be also related to the cooling of the lava field emplaced in the previous days.

INTEGRATED SATELLITE-DATA-DRIVE RESPONSE TO EFFUSIVE CRISIS AT PITON DE LA FOURNAISE

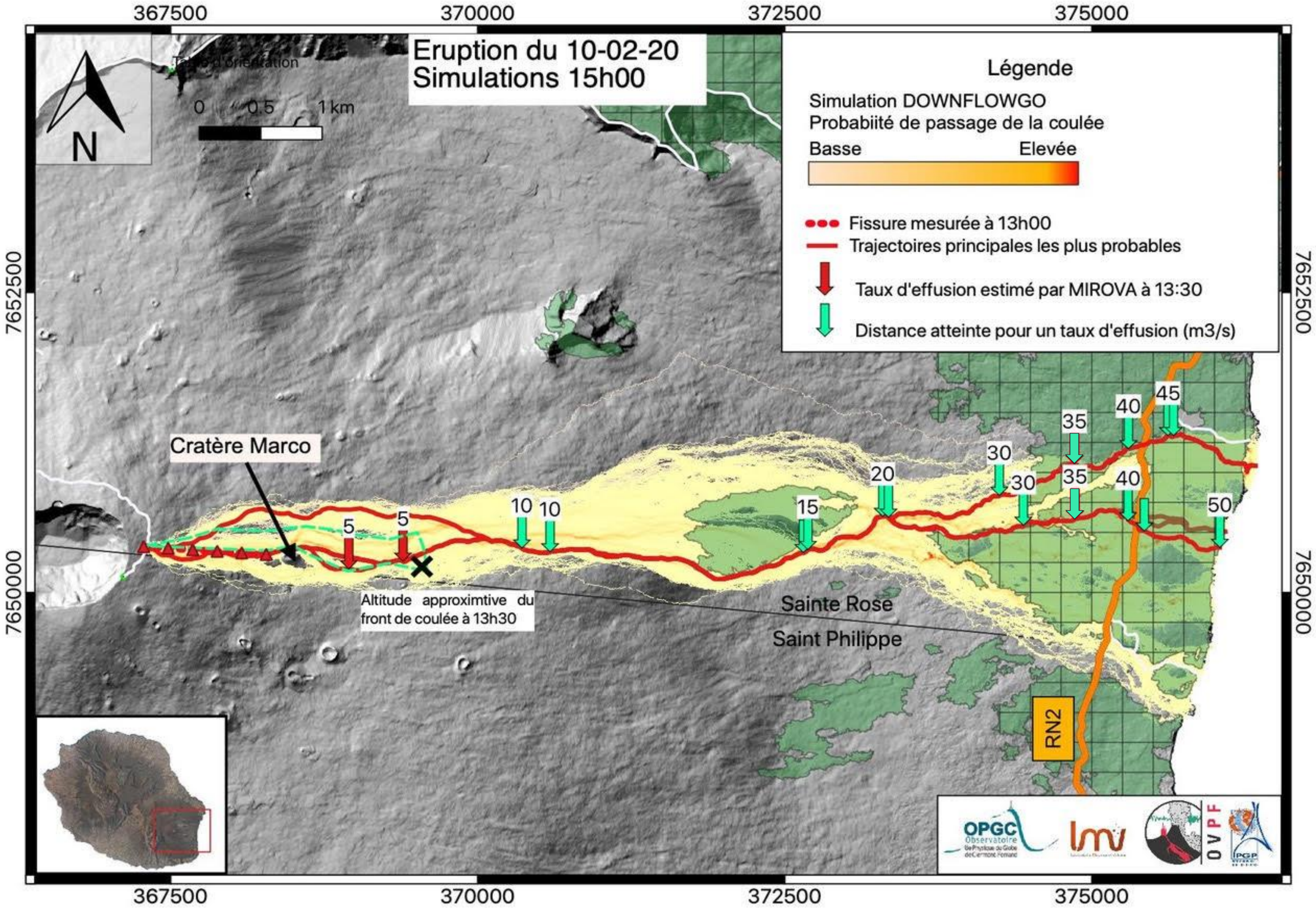




from Harris et al. 2019

NEAR REAL TIME PROTOCOL IN ACTION: ERUPTION OF 10 FEBRUARY 2020

This map was map delivered to the Observatory **about 4 hours after** the start of the eruption



Map generated by Oryaëlle Chevrel

NEAR REAL TIME MONITORING OF EFFUSIVE ERUPTIONS AT STROMBOLI VOLCANO

LGS Laboratorio Geofisica Sperimentale

UNIVERSITÀ DEGLI STUDI FIRENZE DST DIPARTIMENTO DI SCIENZE DELLA TERRA

PROTEZIONE CIVILE Presidenza del Consiglio dei Ministri Dipartimento della Protezione Civile

COMUNICATO N.15 ATTIVITA' VULCANO STROMBOLI DELLE 21:30 (ORA LOCALE) DEL 17/07/2019

Wednesday, 17 July 2019 Massimo Della Schiava Stromboli, Volcano monitoring, infrasound, Projects 1914 Hits

I dati termici da satellite e da telecamera registrati nelle ultime 12 ore indicano un aumento dell'attività effusiva dal Cratere di SW. Le immagini MODIS acquisite nelle ultime 12h, in favorevoli condizioni meteorologiche e di geometria satellitare, mostrano anomalie termiche elevate di 466 MW (09:40 UTC) e 744 MW (01:50 UTC).
Tale incremento dell'attività termica corrisponde ad un incremento dell'attività effusiva, con tassi effusivi (TADR) stimati in circa 2 mc/s (+/- 0.6 m3/s).

Sulla base dei dati rilevati dal MODIS, il volume totale di materiale emesso è pari a circa 1.3 Mmc (+/- 0,4 Mmc) (Figura 1).

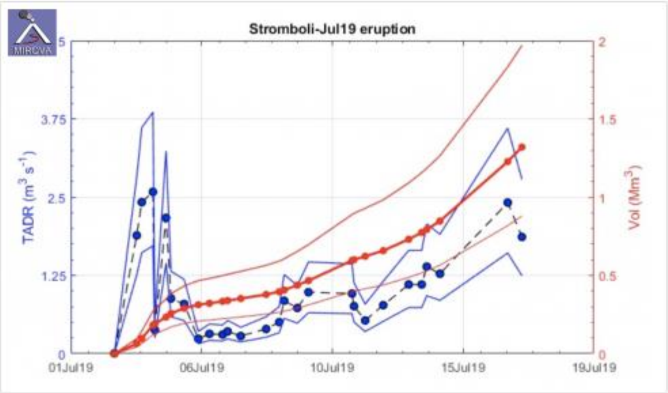


Figura 1. Andamento del tasso effusivo medio (Time Averaged Discharge Rate) e volumi di lava eruttati a partire dal 4 Luglio 2019 (stime preliminari ricavate dai dati MODIS-MIROVA)

L'incremento della radianza termica misurata dal MODIS è confermata dall'immagine SENTINEL acquisita alle 10:00 UTC di oggi che mostra un chiaro aumento dell'area della colata (Figura 2).

Dalle immagini è possibile stimare una lunghezza massima del flusso di circa 600 m e una larghezza massima di 80 m. Il fronte lavico si assesta ad una quota di circa 300 m.

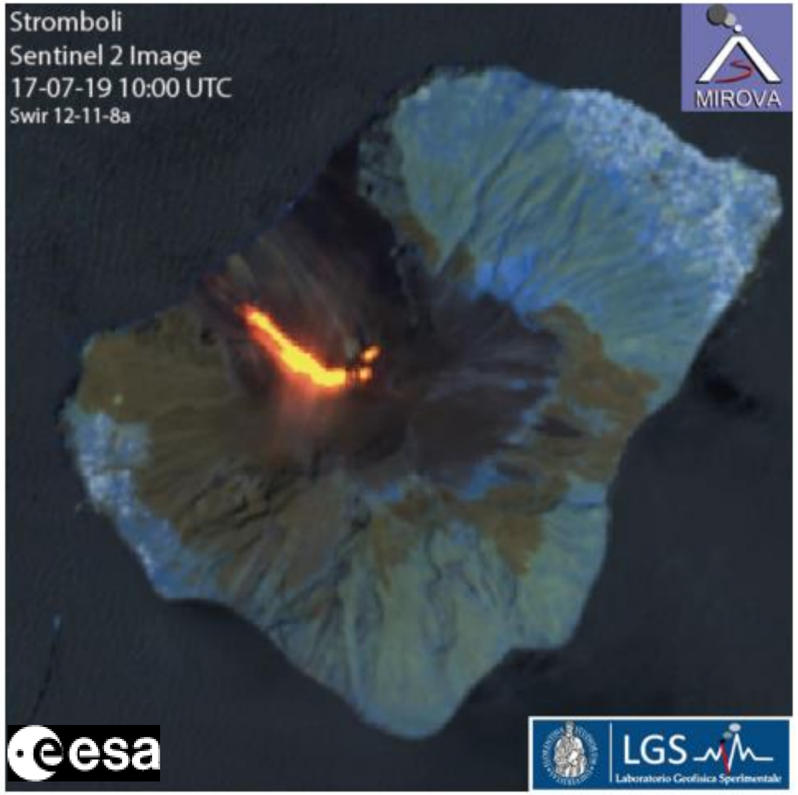
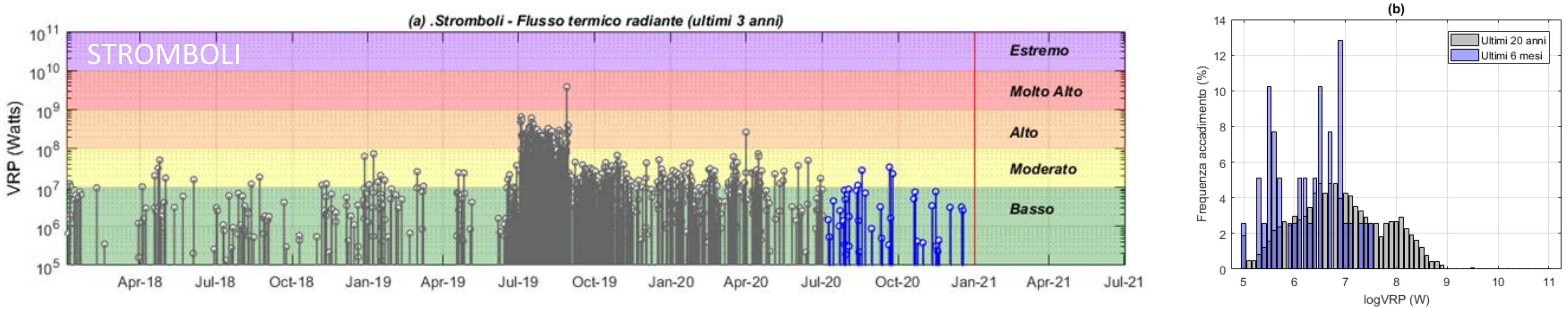
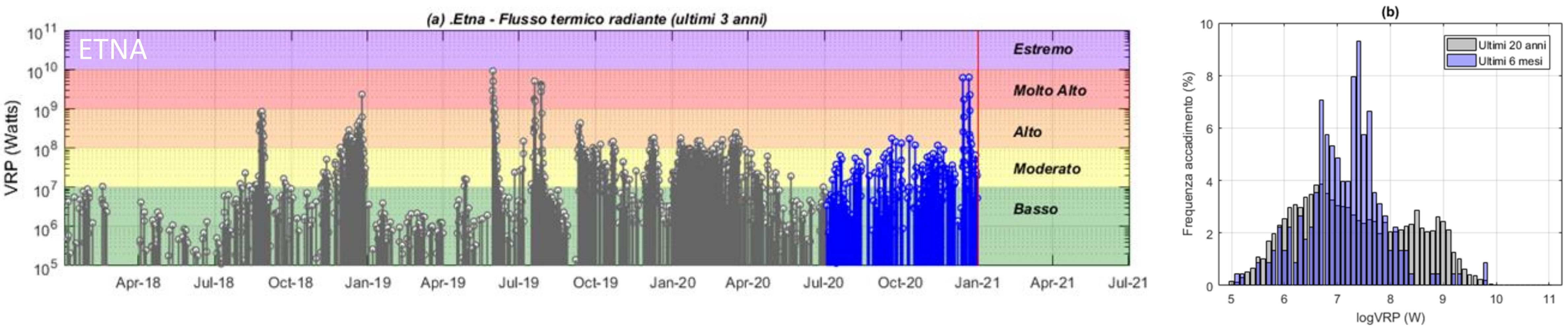


Figura 2. Immagine SENTINEL della colata dal cratere di SW acquisita alle 10:00 UTC del 17/07/2019 (MIROVA –UNITO).

lgs.geo.unifi.it/index.php/blog/comunicato-stromboli-17-luglio-h2130

STATISTICAL ANALYSIS AND REPORTS: The example of STROMBOLI and ETNA volcanoes





Data elaborated by M. Laiolo

What next?

1. **Filling the gaps in the MODIS-MIROVA dataset** for 100 volcanoes during the period 2000-2020:

- About 60% volcanoes currently monitored by MIROVA does not have the full dataset processed
- Gradual publication of the database, once the collection is complete and supervised
- Sharing of the database with other systems

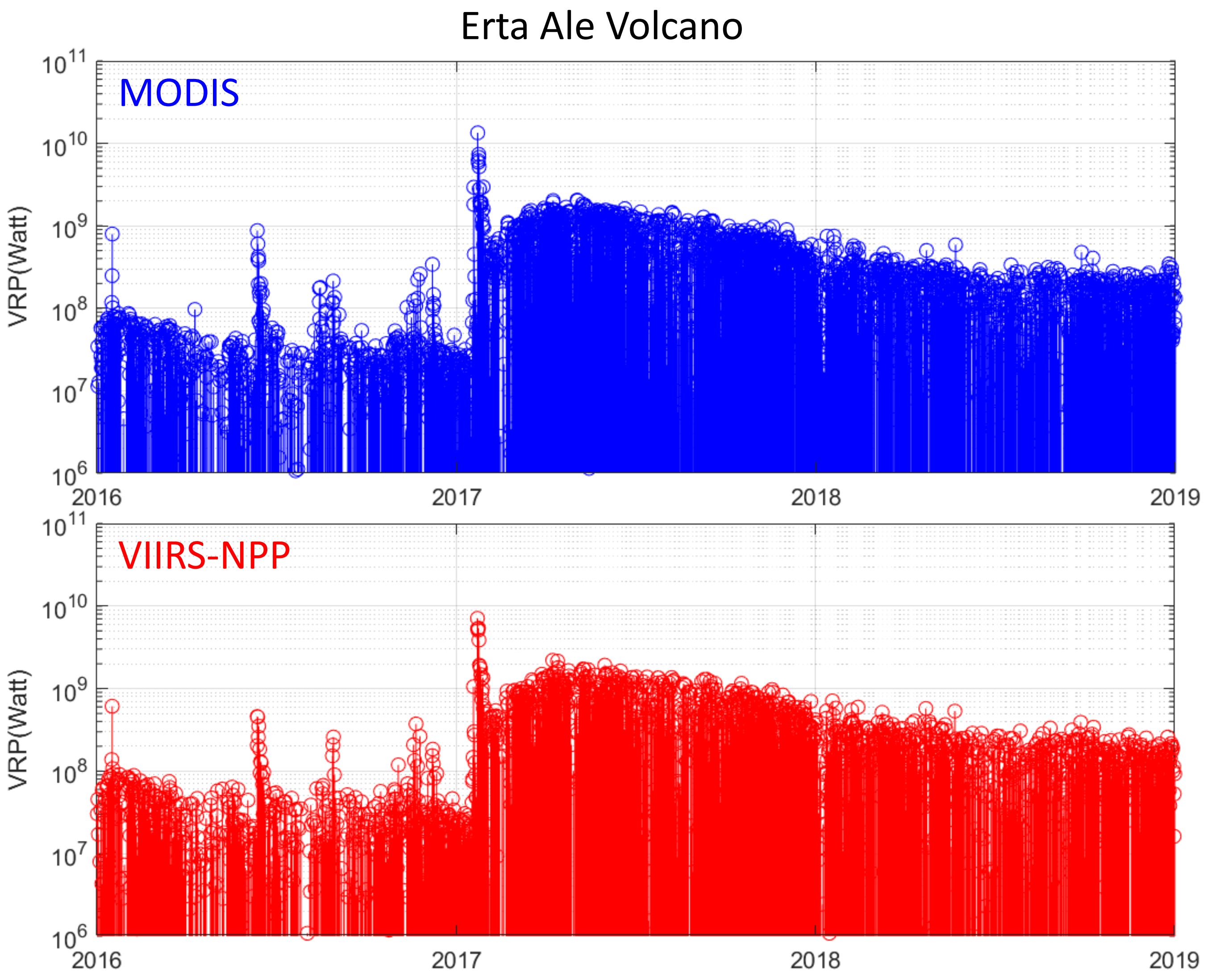
2. **Transition MODIS to VIIRS**

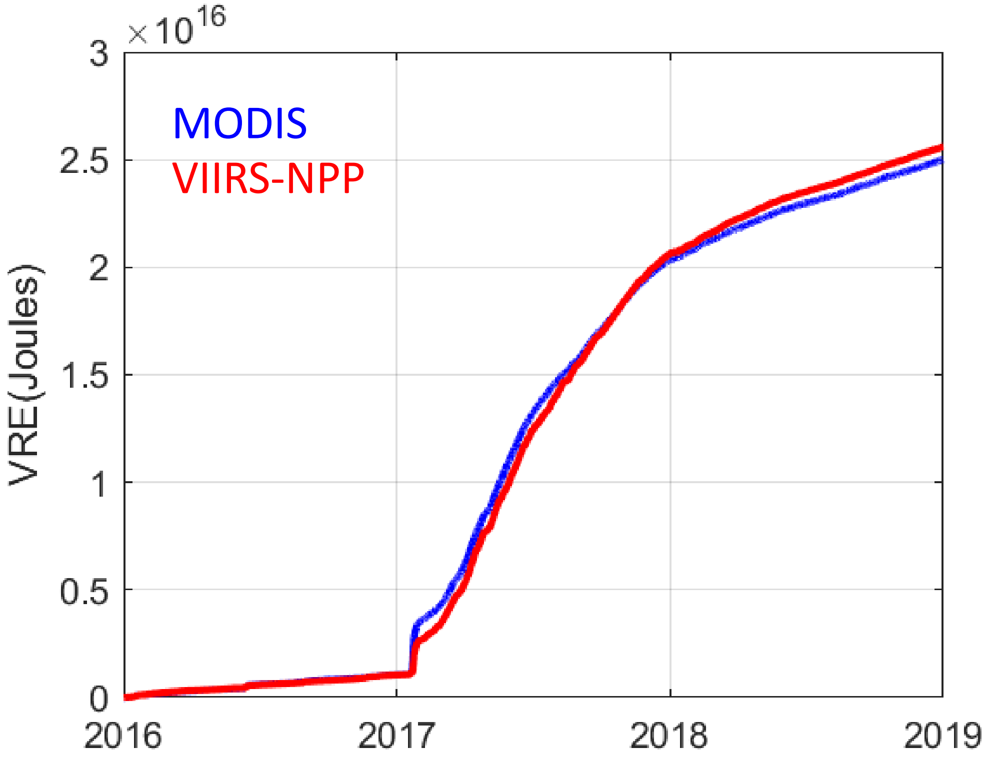
- VIIRS will provide VRP data in excellent continuity with MODIS.
- Currently we are in the validation stage of MIROVA algorithm to VIIRS (750 m)
- Implementation of NRT capabilities for VIIRS (750 m)
- Exploiting the capabilities of VIIRS 375 m, for early detection of thermal unrest

3. **Implementation of LANDSAT 8 (SWIR) –** Validation Stage

4. **Implementation of SENTINEL 3 (MIR)** – In collaboration with MOUNTS platform

Transition MODIS to VIIRS: Preliminary validation





Data elaborated by A. Campus