Multi Scale Multi Temporal Approach for Volcanic Eruptions monitoring using Optical Satellite data

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Summary

- INGV Multi scale and multi temporal optical satellite monitoring of volcanoes
- processing chain for surface temperature analysis within ESA-GEP project
- Active lava flows monitoring on Etna and Kilawea volcanoes
- ESA-VEGAN project products and achievments

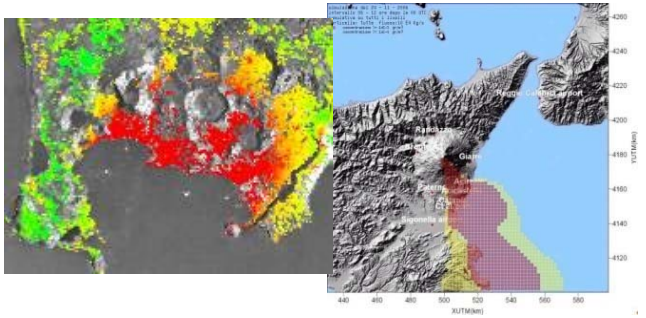
RISK PHASES	SERVICES	PRODUCTS

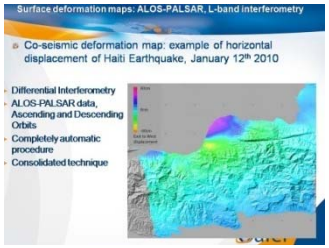
Knowledge & Prevention

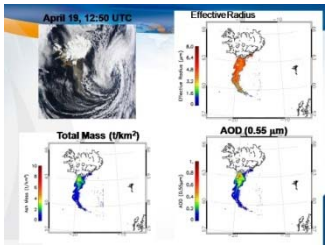
CRISIS

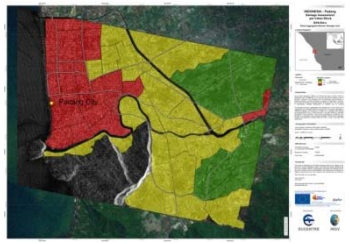
Post crisis

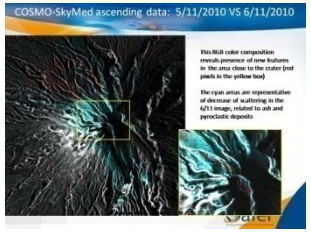
Service / Product **Volcano**
DIFSAR velocity map Thermal mapping Degassing plumes
DIFSAR surface displacement maps Effusion rate Volcanic clouds (ash, so2)
Change detection Maps New lava flows Ash cover New surface morphology











EMERGENCY CORE SERVICE IMPLEMENTATION

INGV has contributed to COPERNICUS and National Actions focused on the development of integrated system using satellite and ground data

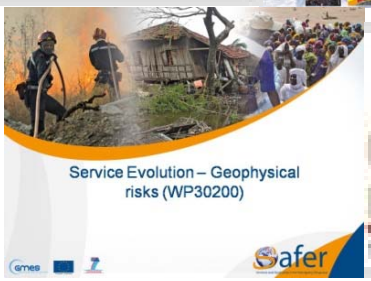
VOLCANO SERVICES

Intial period (2004-2008)

- FP6-PREVIEW
- ASI-SRV

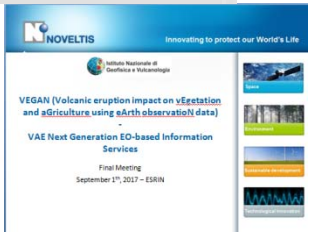
Implementation period and Initial operations (2009-2014)

- FP7-SAFER
- ASI-SRV

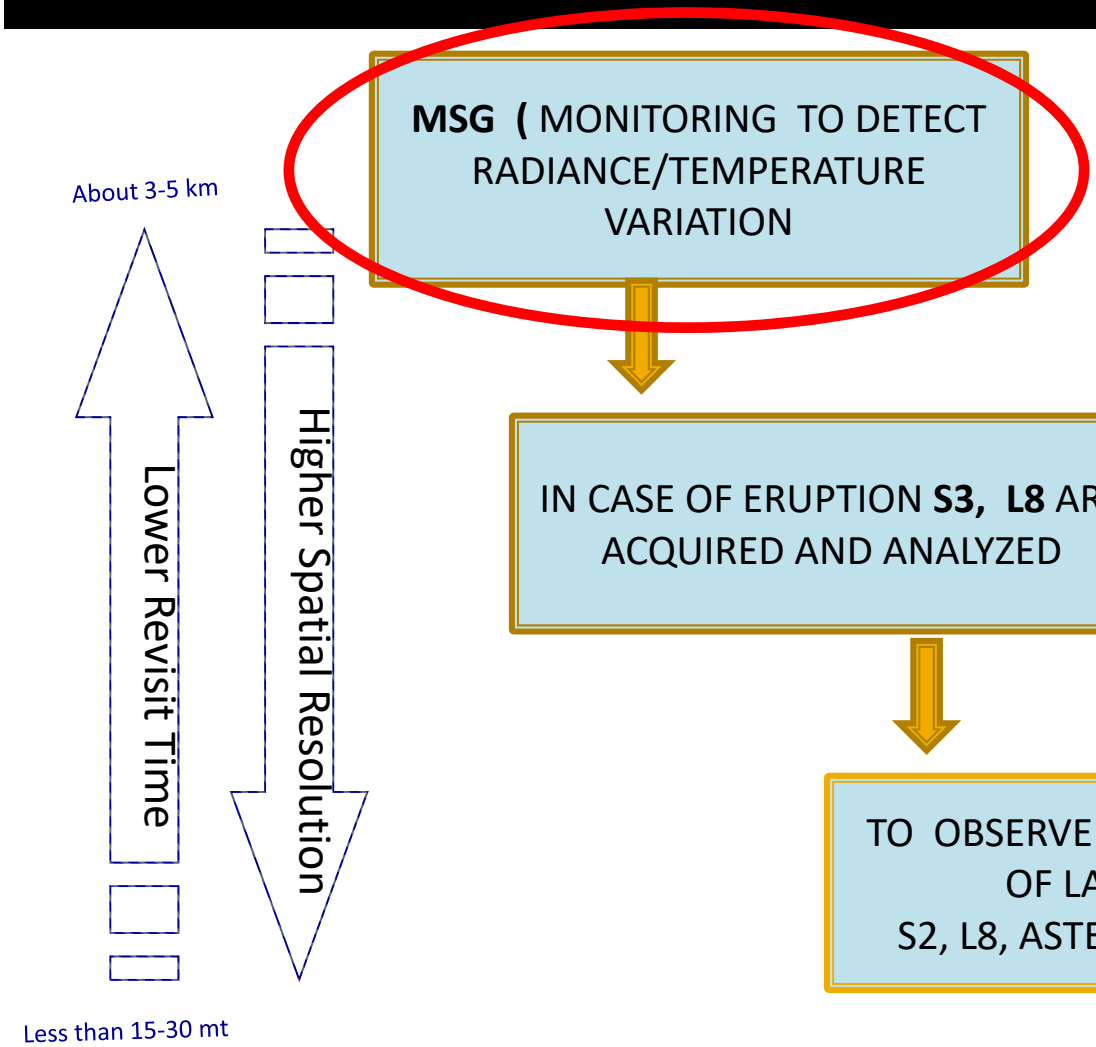


Implementation of systematic porcessing chains (2015-2018)

- ESA-GEP
- ESA-VEGAN



Multi scale and multi temporal optical satellite monitoring approach



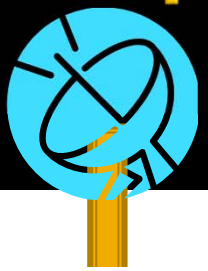
Scheme of volcano Thermal monitoring through satellite data at INGV

SENSOR	SPATIAL RESOLUTION	TEMPORAL RESOLUTION
MSG	3-5 km	5 min

SENSOR	Spatial Resolution (mt)	Temporal Resolution
ASTER	90	16 days
LANDSAT-8	100	16 days
SENTINEL-2	20	About 6 days
SENTINEL-3	1000	2 per days

MS2RWS: Rapid Response Web Service

The service is currently active
On Italian active volcanoes
It coud be activated for other volcanoes of the world
The systems is usefull to get rapid Information on the starting of an eruption and

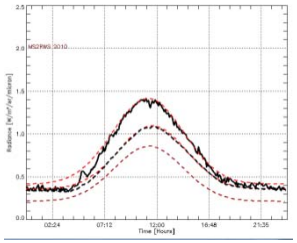


Radiance SEVIRI data

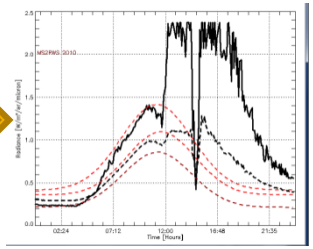
channel extraction

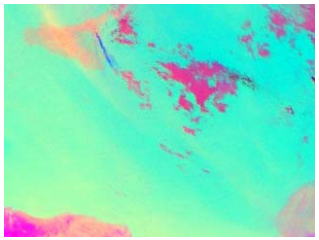
MS2RWS

NO Eruption

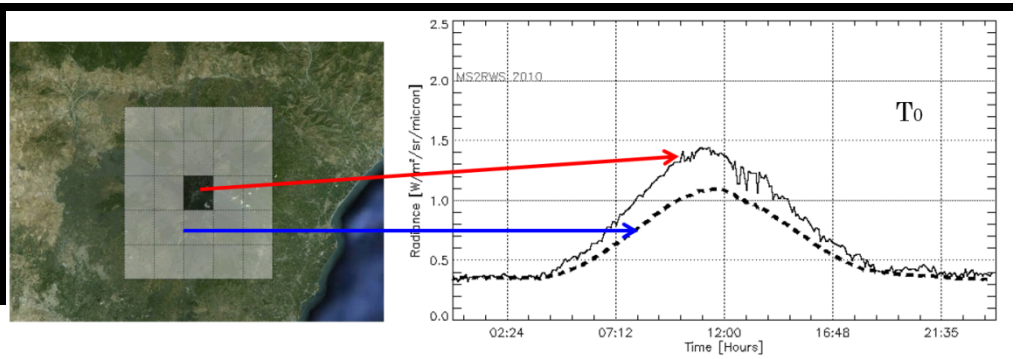


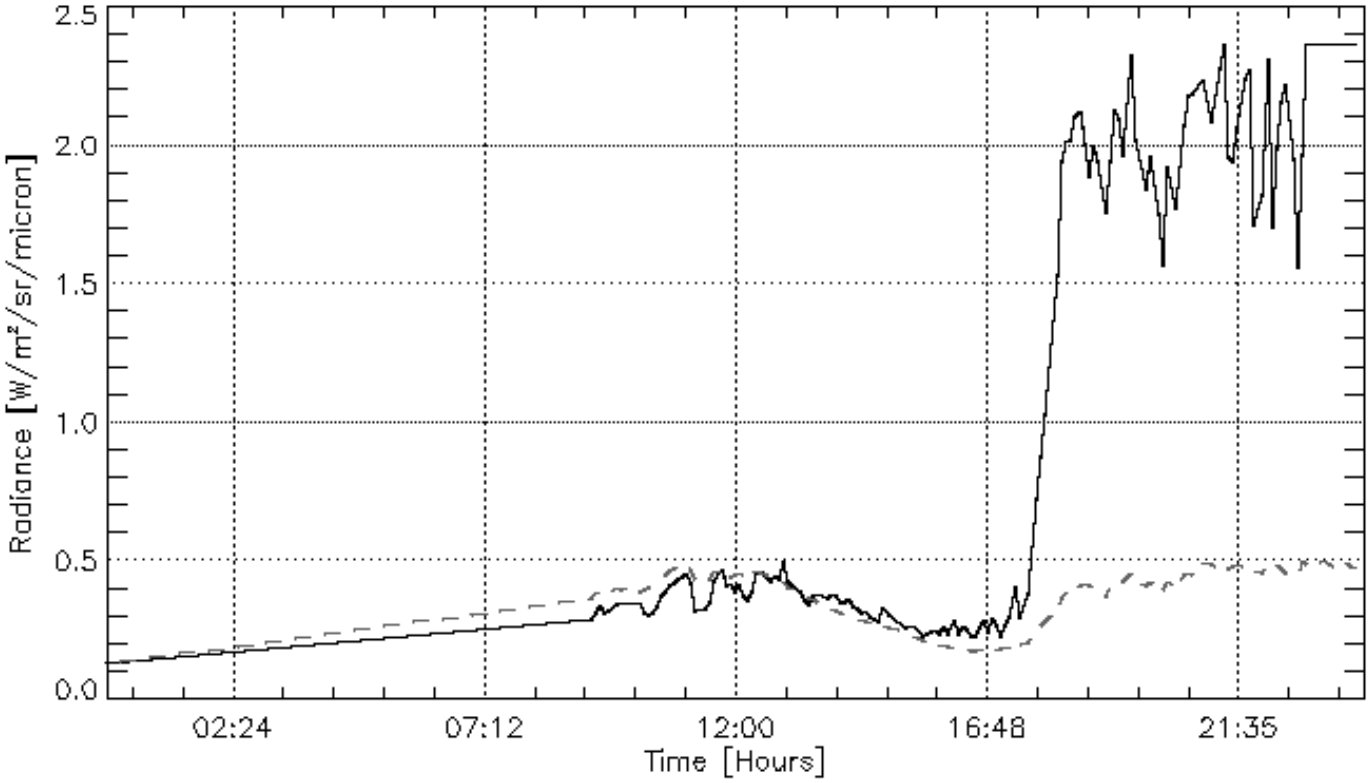
Eruption



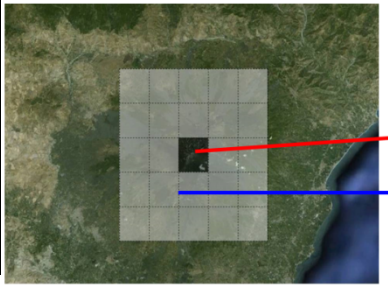


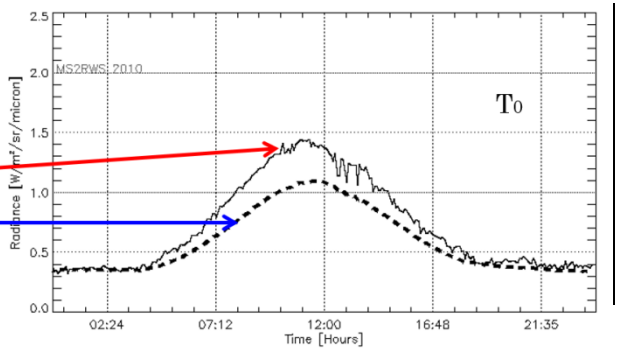
2017 February 27
Etna eruption

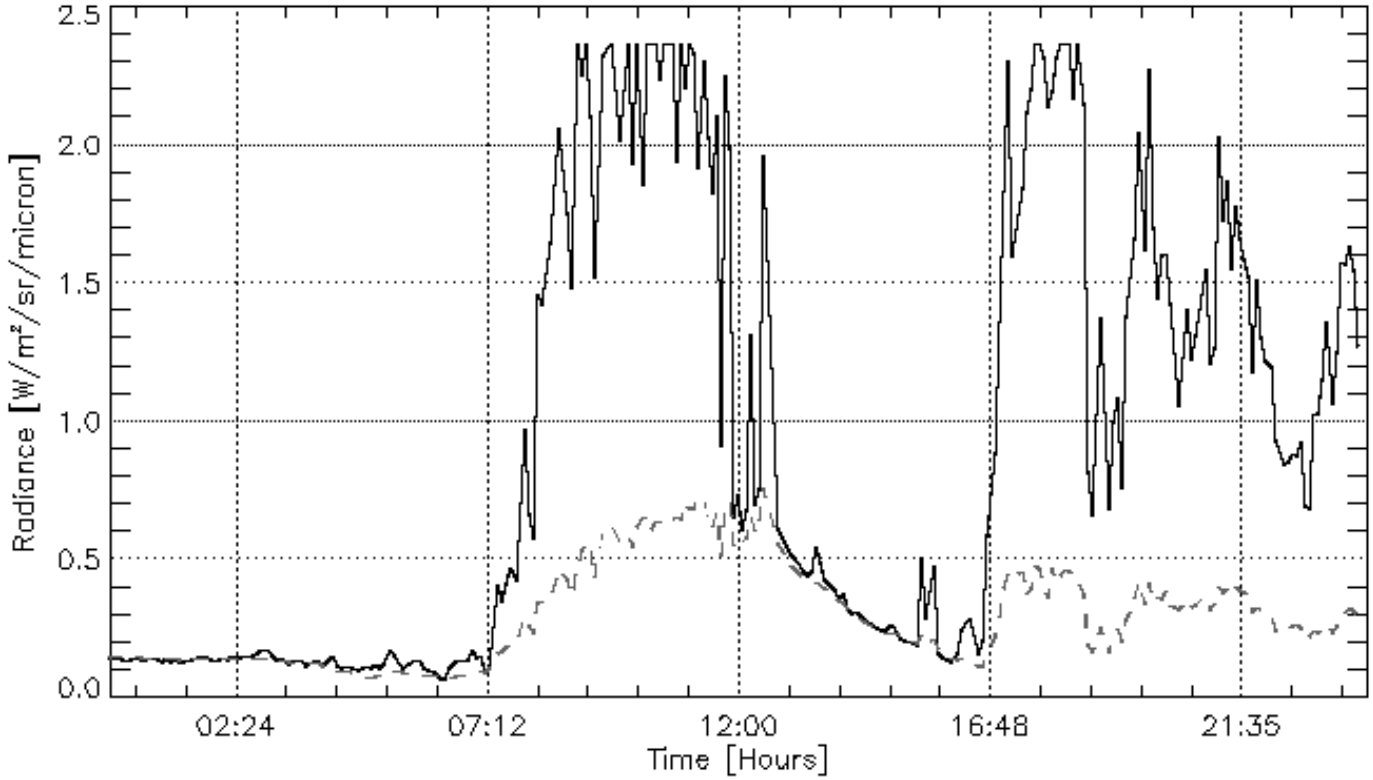




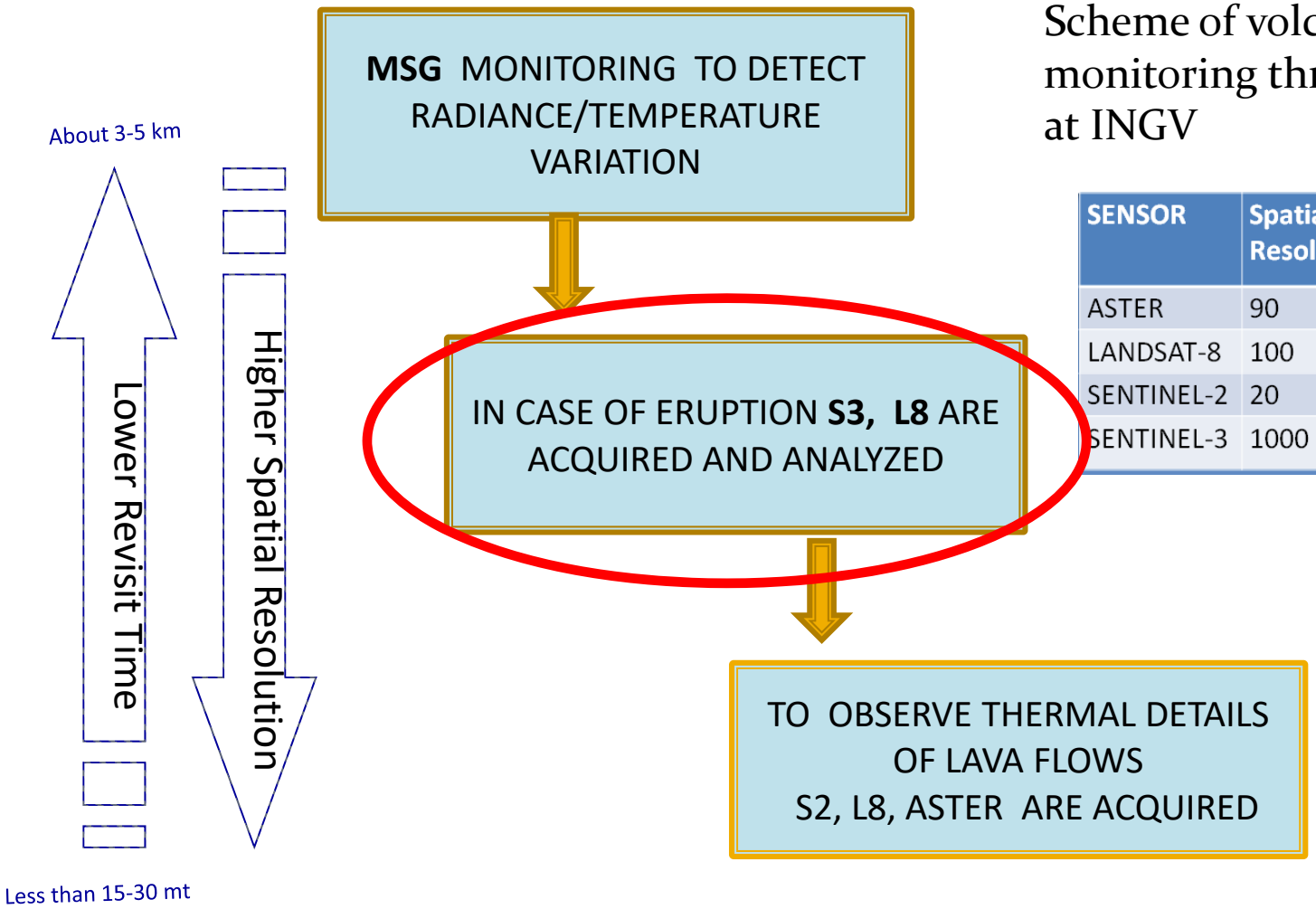
2017 March 15







Multi scale and multi temporal satellite monitoring



Scheme of volcano Thermal monitoring through satellite data at INGV

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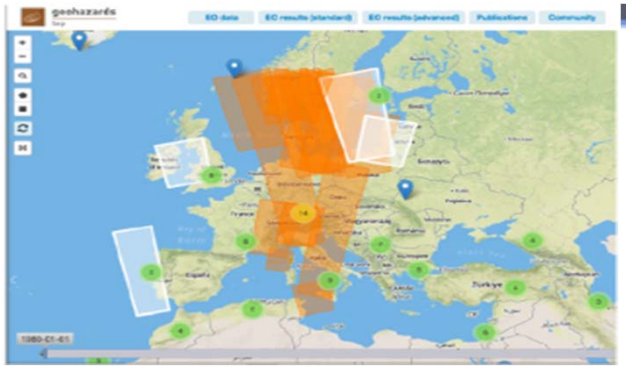
ESA Geohazards Exploitation Platform (GEP)

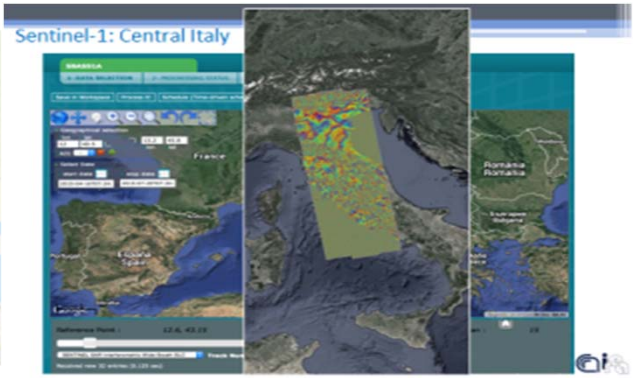
geohazards tep

ESA funded the development of an innovative tool (GEP) to demonstrate the benefits of a satellite data exploitation platform for large scale hazards mapping and monitoring and to link with Science and User networks.

The GEP Platform allows

- on demand processing for specific user needs and systematic processing to address common information needs of the geohazards community as a whole
- massive processing on multi-tenant computing resources on the Cloud that will address the challenges of monitoring tectonic areas on a global basis, and of studying a range of geohazards.





GEP and STEMP

- In the context of the VOLcanoes Thermal Application (VOLTAGE) for GEP has been implemented.
- INGV has setup an end-to-end processing chain (STEMP) for the generation of surface temperature maps over volcanic areas.

- STEMP generates:
  - Surface temperature map from ASTER, Landsat-8, Sentinel-3 (volcanic activity early warning studies)
  - Hot Spot and Lava flow detection with Sentinel-2.

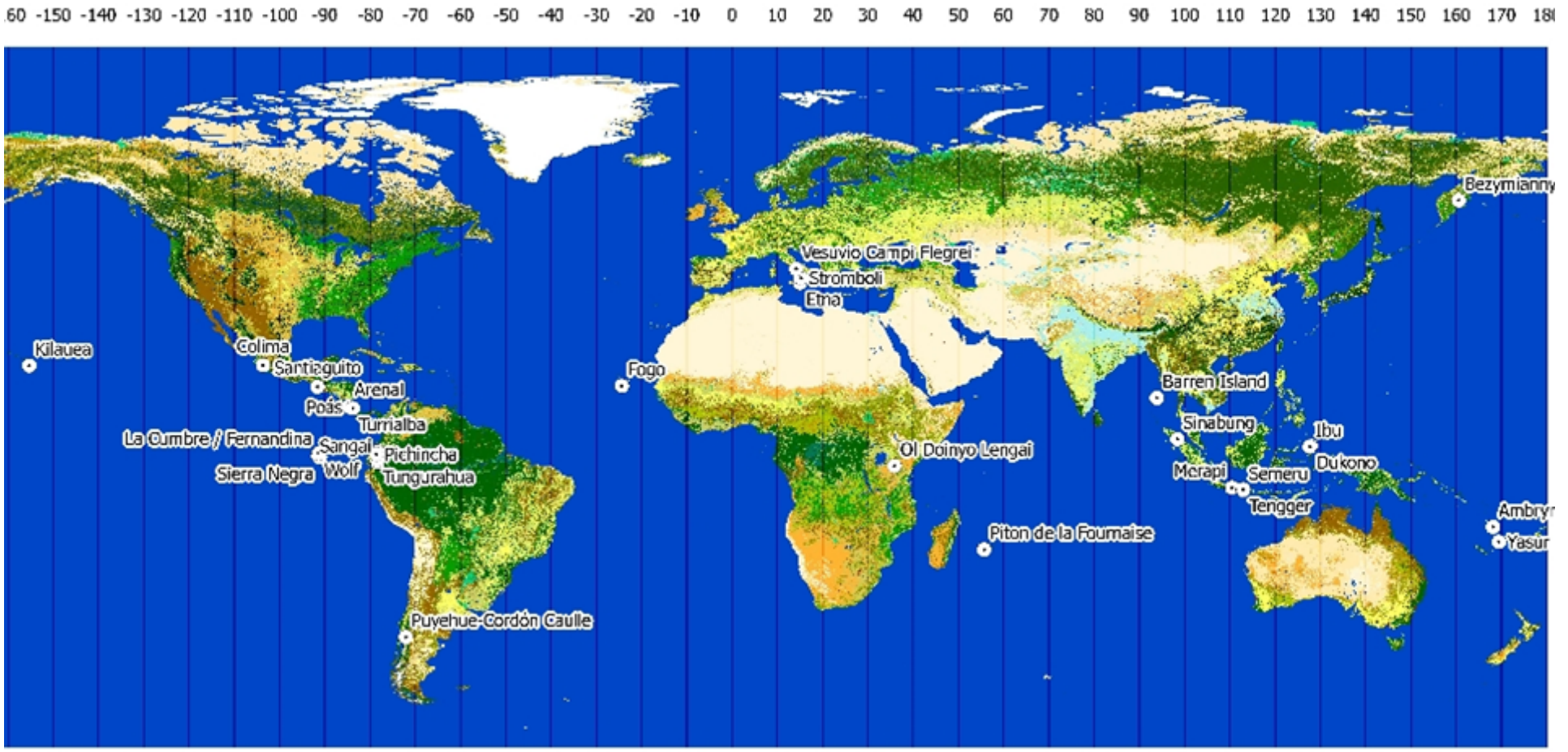
VOLCANOES SELECTED FOR TO TEST STEMP PRODUCTS (1/2)

Selection for GEP [Y / N / M]	Volcano	Area	Country	Region	Elevation
N	Fogo	Fugo Island	Cape Verde	Africa	2829 m
Y	Puyehue-Cordón Caulle	Región de Los Ríos	Chile	Latin America	2236 m
Y	Arenal	Alajuela	Costa Rica	Latin America	1670 m
Y	Poás	Alajuela	Costa Rica	Latin America	2708 m
Y	Turrialba	Cartago	Costa Rica	Latin America	3340 m
Y	La Cumbre / Fernandina	Galápagos, Isla Fernandina	Ecuador	Latin America	1476 m
Y	Sangai	Morona-Santiago Province	Ecuador	Latin America	5286 m
Y	Sierra Negra	Galápagos, Isla Isabela	Ecuador	Latin America	1124 m
N	Wolf	Galápagos, Isla Isabela	Ecuador	Latin America	1710 m
Y	Piton de la Fournaise	La Réunion	France	Africa	2632 m
Y	Santiaguito	Quetzaltenango	Guatemala	Latin America	2550 m
N	Barren Island	Andaman Islands	India	South Asia	354 m
Y	Dukono	Halmahera	Indonesia	SE Asia	1229 m

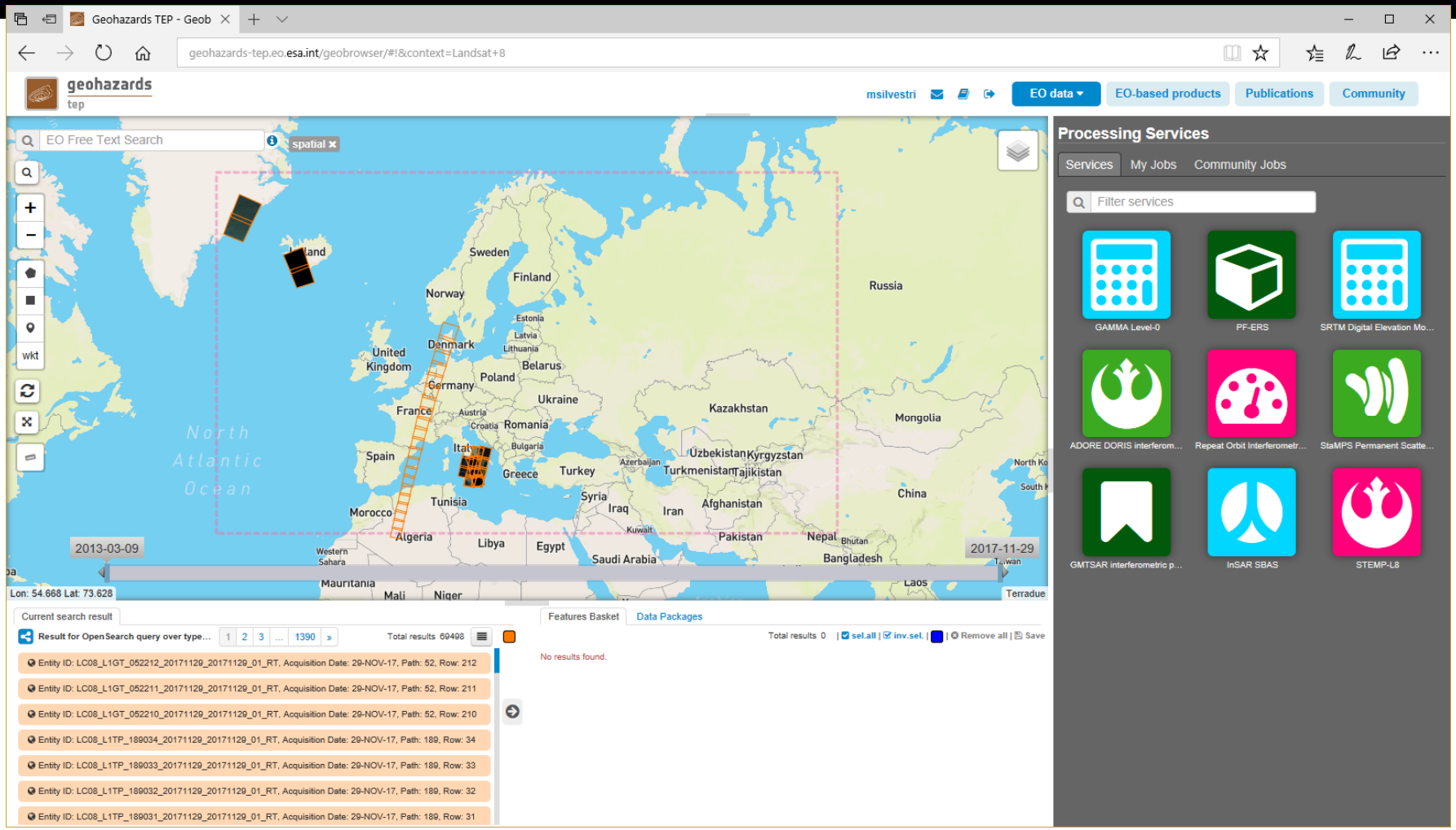
VOLCANOES SELECTED FOR TO TEST STEMP PRODUCTS (2/2)

Y	Ibu	Halmahera	Indonesia	SE Asia	1325 m
Y	Merapi	Central Java / Yogyakarta	Indonesia	SE Asia	2968 m
N	Semeru	East Java	Indonesia	SE Asia	3676 m
N	Tengger	East Java	Indonesia	SE Asia	2329 m
Y	Etna	Sicily	Italy	Europe	3330 m
Y	Stromboli	Sicily, Aeolian Islands	Italy	Europe	924 m
Y	Vesuvio Campi Flegrei	Naples	Italy	Europe	458 m
Y	Colima	Colima	Mexico	Latin America	3850 m
N	Bezymianny	Kamchatka	Russia	Europe & Central Asia	2882 m
N	Ol Doinyo Lengai	Rift Valley	Tanzania	Africa	2962 m
N	Kilauea	Hawaii	USA	Oceania	1222 m
N	Ambrym	Malampa Province	Vanuatu	Oceania	1334 m
N	Yasur	Tanna	Vanuatu	Oceania	361 m
Y	Cotopaxi	Cotopaxi Province	Ecuador	Latin America	5911 m
Y	Tungurahua	Tungurahua Province	Ecuador	Latin America	5023 m
Y	Reventador	Napo Province	Ecuador	Latin America	3562 m
Y	Cotacachi	Imbabura Province	Ecuador	Latin America	4944 m
N	Pichincha	Pichincha Province	Ecuador	Latin America	4784 m
Y	Sinabung	Sumatra Utara Province	Indonesia	SE Asia	2460 m
Y	Chachimbiro	Imbabura Province	Ecuador	Latin America	4106 m

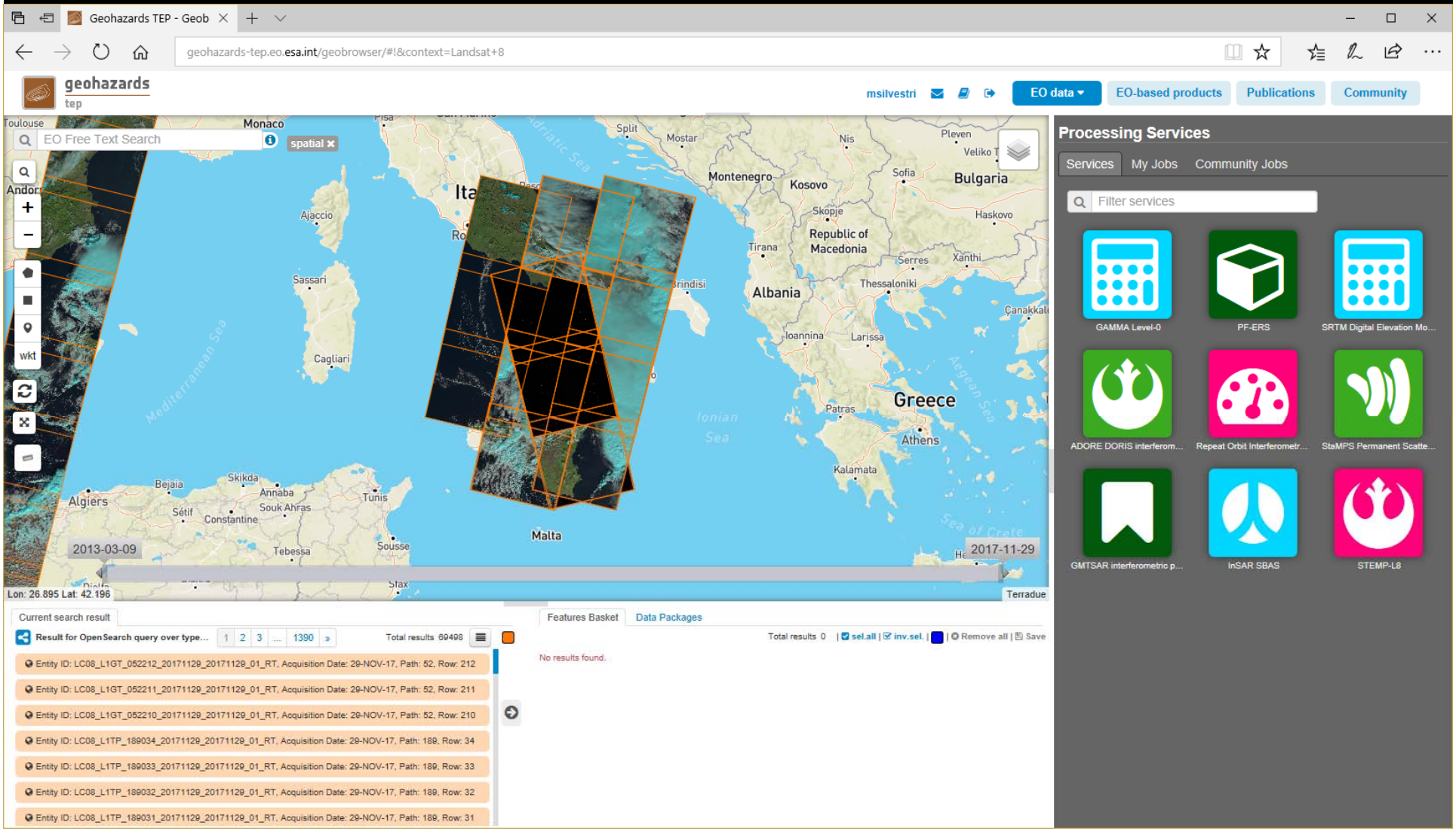
Volcano location Map



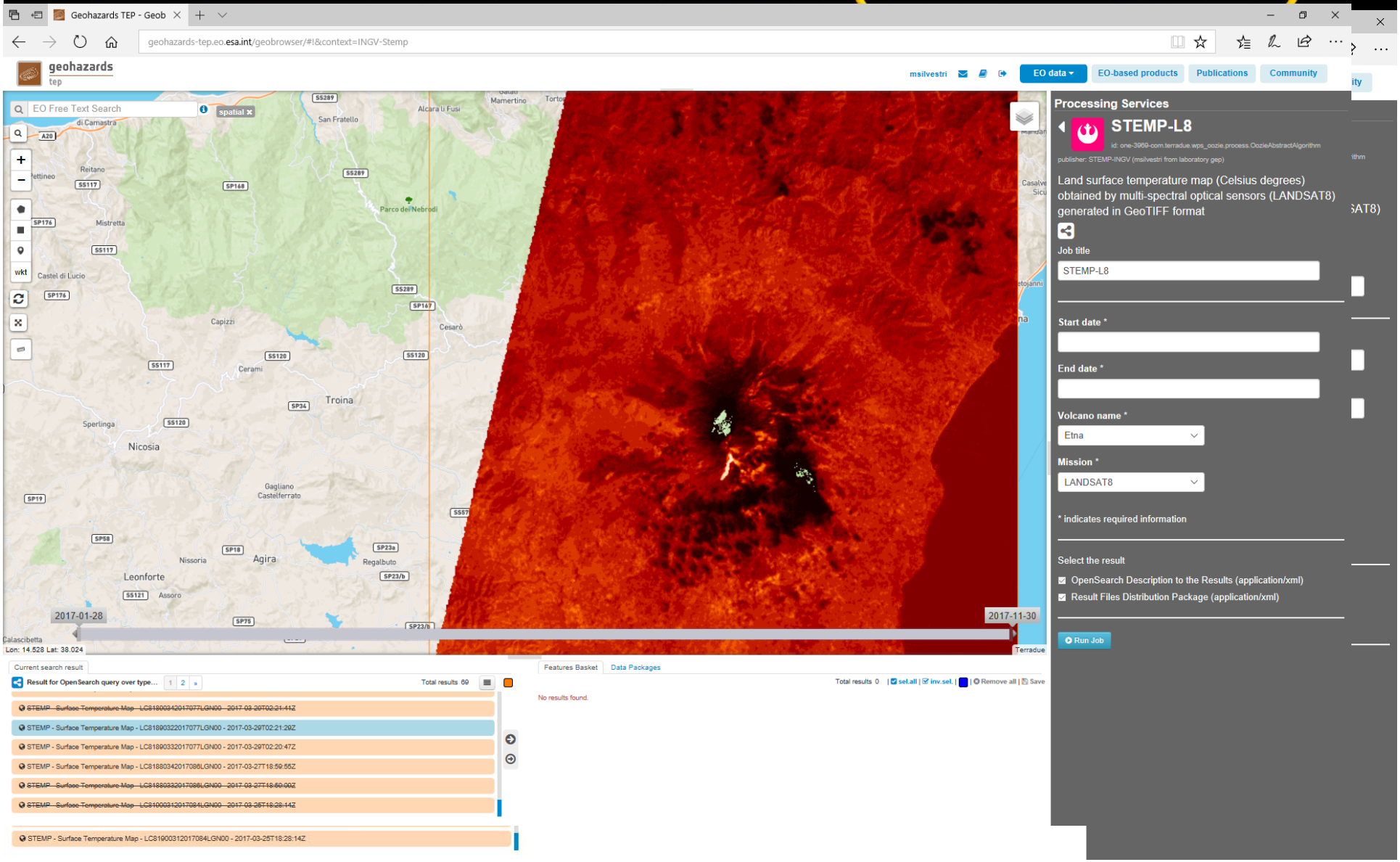
INGV-STEMP implementation on Geohazards Exploitation Platform (GEP)



GEP: Data List (e.g.L8)



From Data to Product (based on L8)

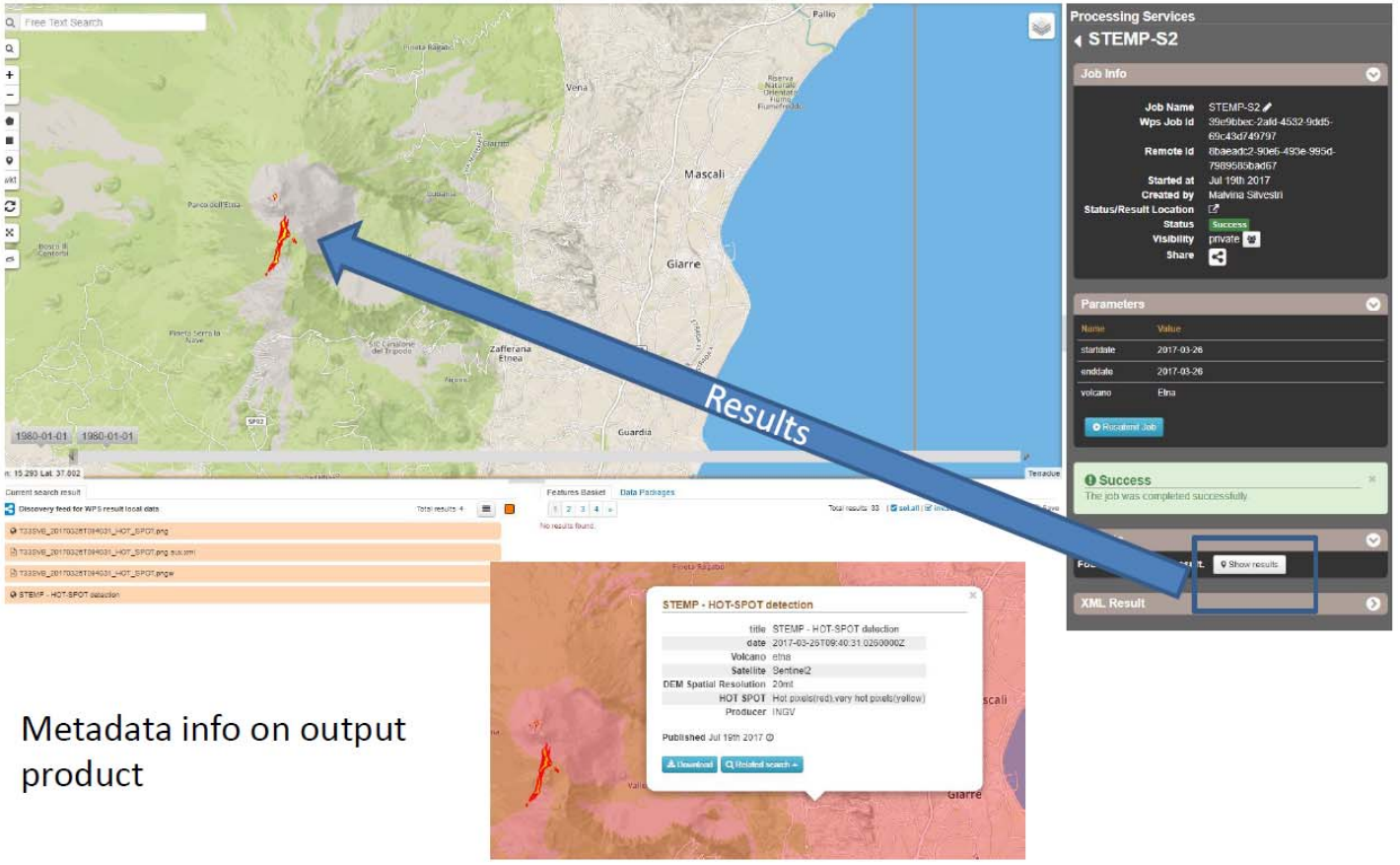


From Data to Product (based on S2)

STEMP-S2

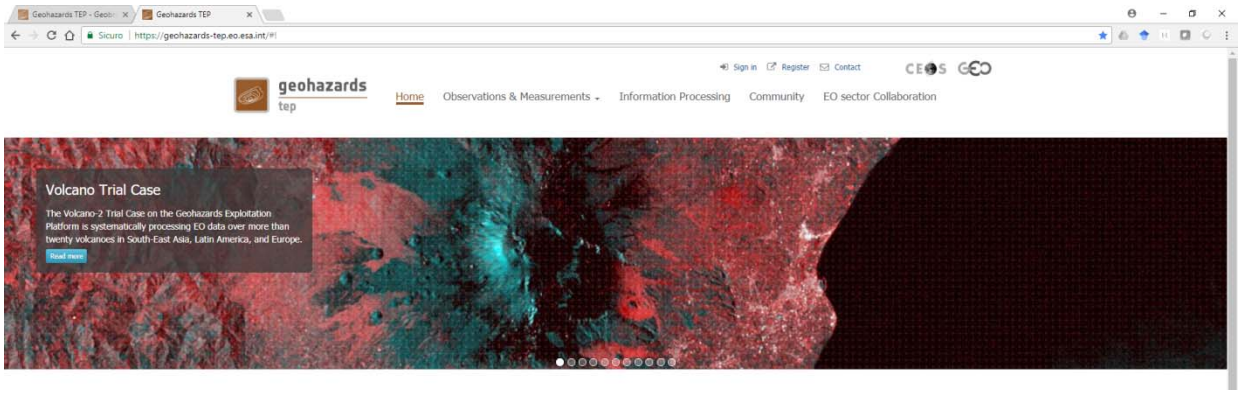
STEMP-S2 in case of eruption with Sentinel-2 data

geohazards tep



Metadata info on output product

https://geohazards-tep.eo.esa.int/#!



DISCUSS 20 **Volcano Trial Case on GEP: Systematically processing EO data**

gep-blog

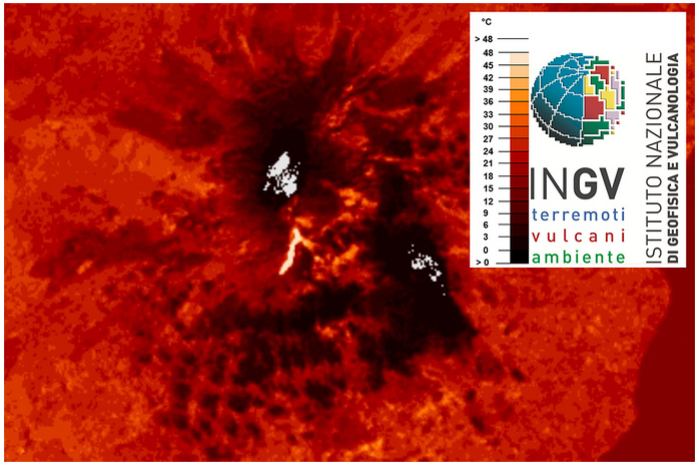
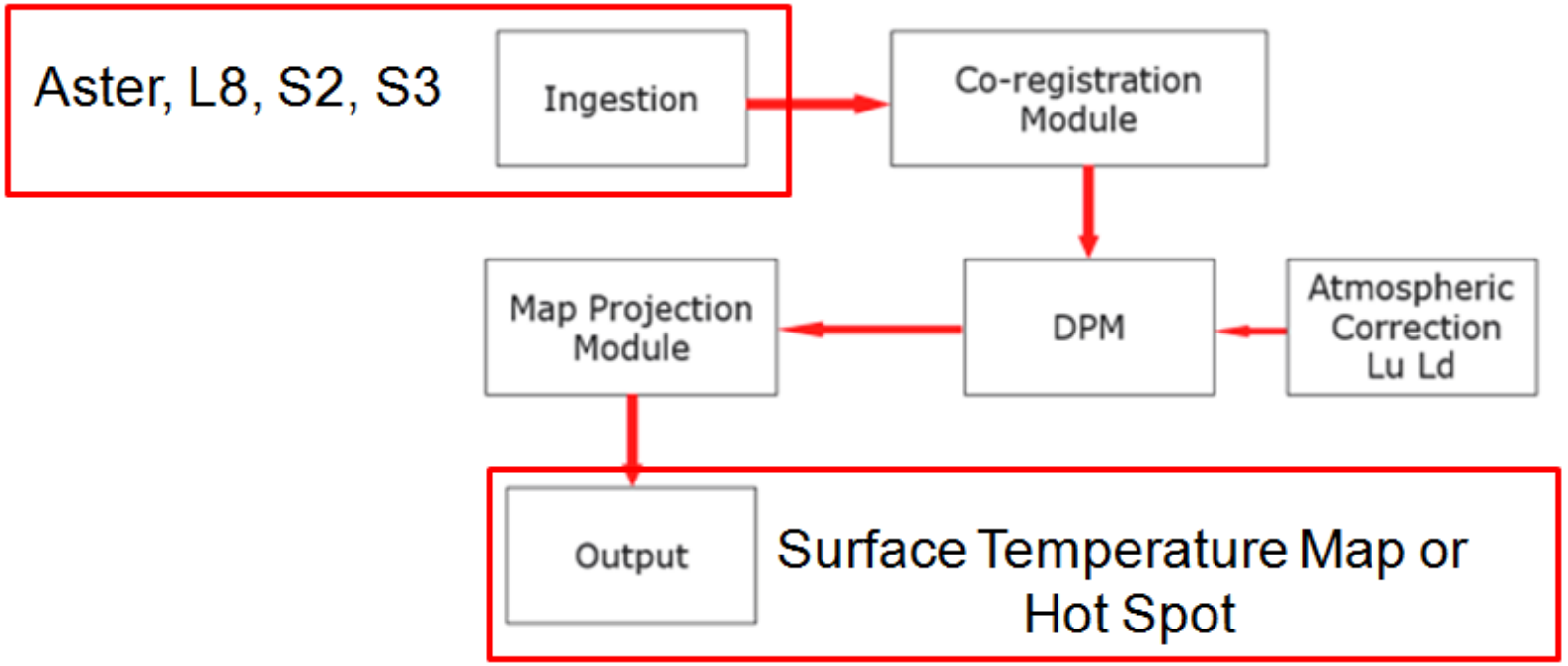


Figure 2: Surface Temperature Map of 27th March 2017 of the volcano Etna. It was created with the INGV STEMP service, a systematic processing chain on GEP. The lava flow in bright white-yellow is clearly visible in the middle of the image.

Data and methods

- DEM for the topography
- In situ atmospheric parameter data to remove the effect of the atmosphere on the EO satellite data.
- Surface Temperature Map produced following Gillespie et al., (1998), Barsi et al., (2003) using TIR channels
- Hot Spot Map produced following Murphy et al., 2016 using VNIR-SWIR channels



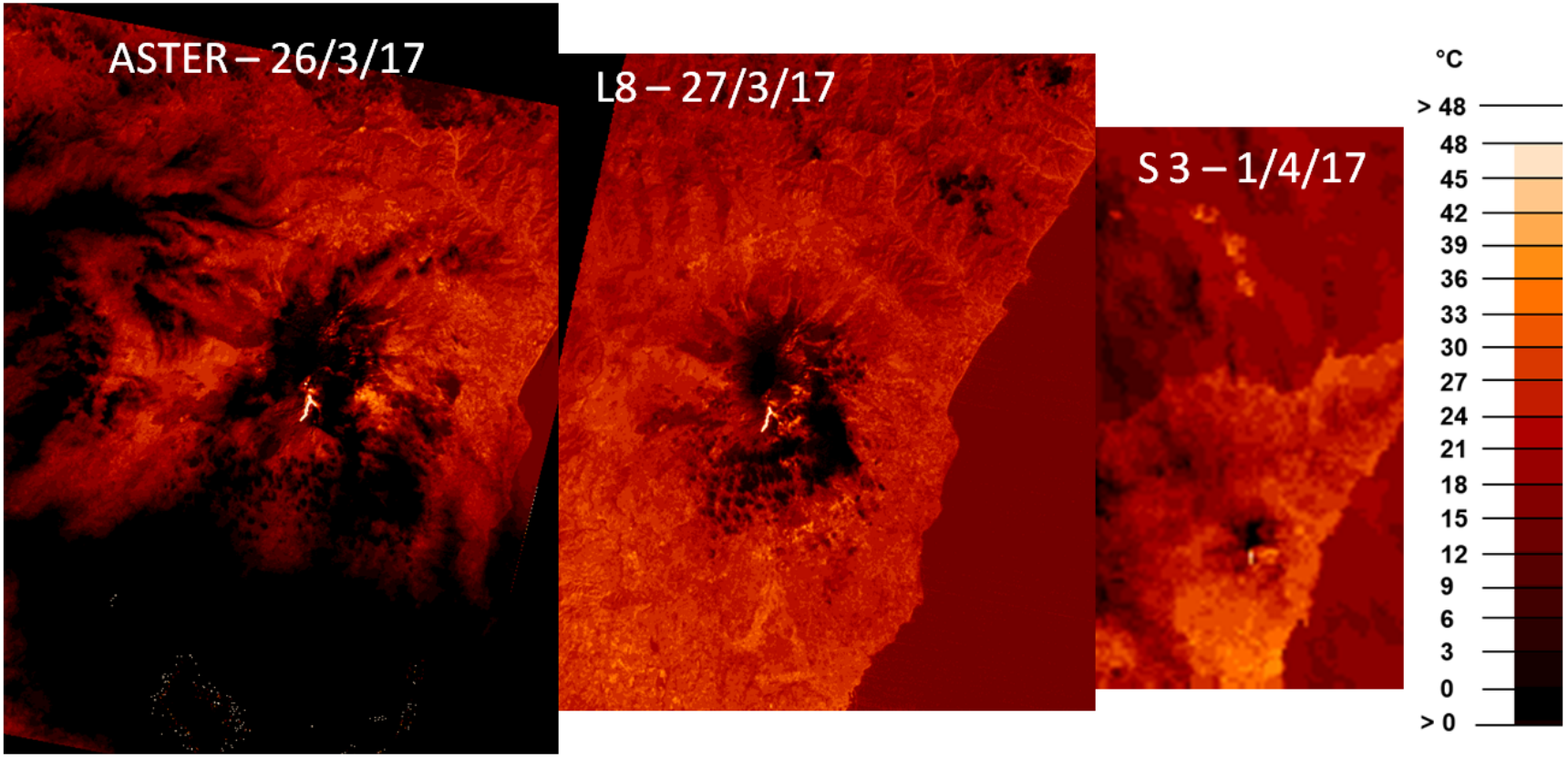
Surface Temperature map: Temperature Emissivity Separation

- Atmospheric correction using MODTRAN and daily atmospheric profile have been considered

- For this analysis the images acquired during the nighttime pass have been considered because the "contamination" of reflected solar radiation is not present.

Surface Temperature map comparing different satellite data

Surface temperature using ASTER, L8, S3 on Mt. Etna volcano during the last eruption in 2017(daytime acquisition)



Results:

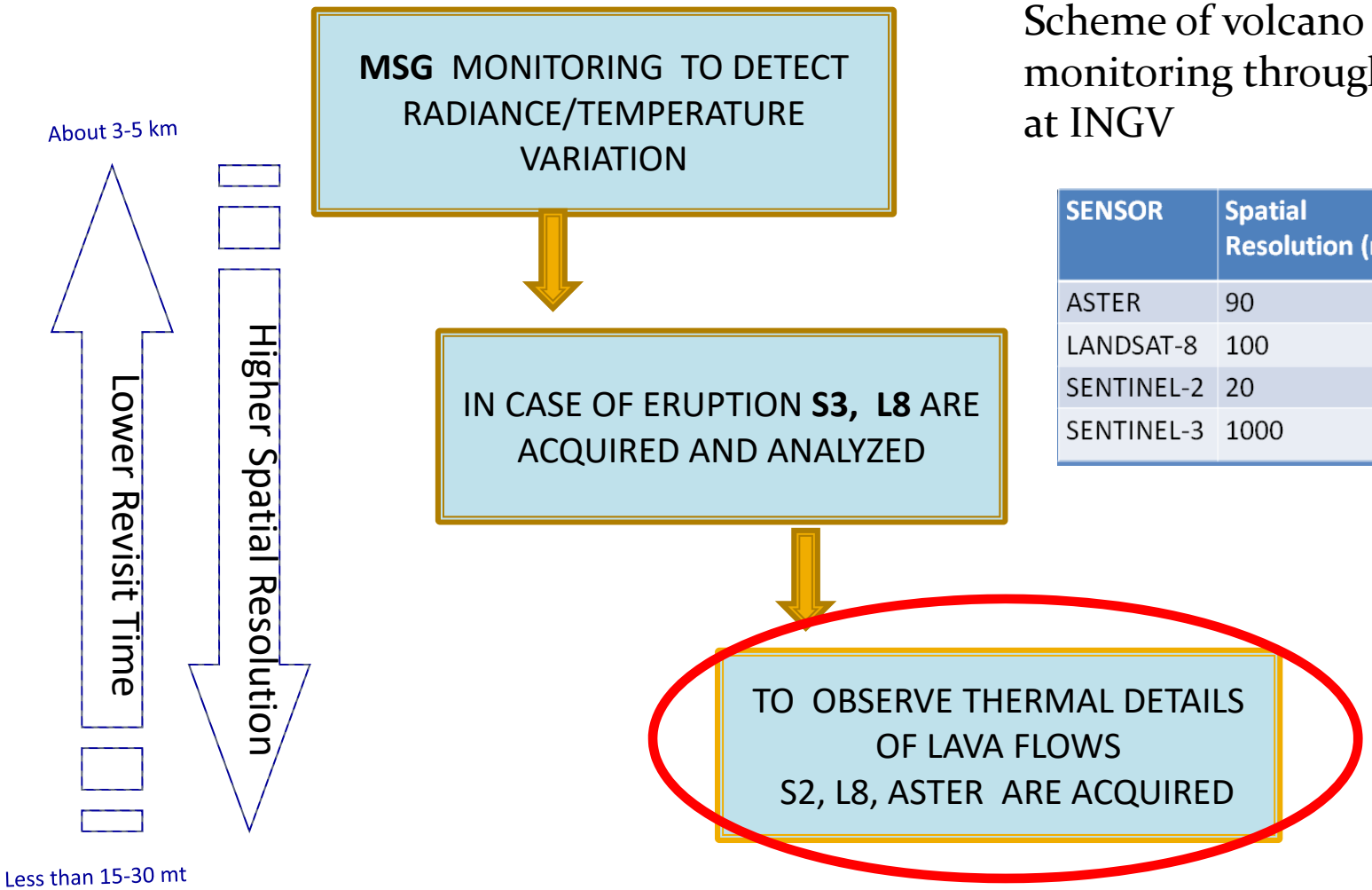
- ASTER and L8 have been scaled at ASTER-TIR channel spatial resolution (90 m).

- Using two different methods (TES, BARSI) the difference in retrieved temperature show an average of less than 1°C for Mt Etna. Comparison with ground measurements also demonstrated good agreement considering that ground measurements represent very small areas compared to the satellite pixel size.

- The results obtained are very useful to understand variability of LST retrievals by remote sensing data

- They highlight the importance of precise emissivity inputs to the retrieval procedures as well as the needs of systematic calibration areas for LST satellite retrievals

Multi scale and multi temporal satellite monitoring



Scheme of volcano Thermal monitoring through satellite data at INGV

SENSOR	Spatial Resolution (mt)	Temporal Resolution
ASTER	90	16 days
LANDSAT-8	100	16 days
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SENTINEL-3	1000	2 per days

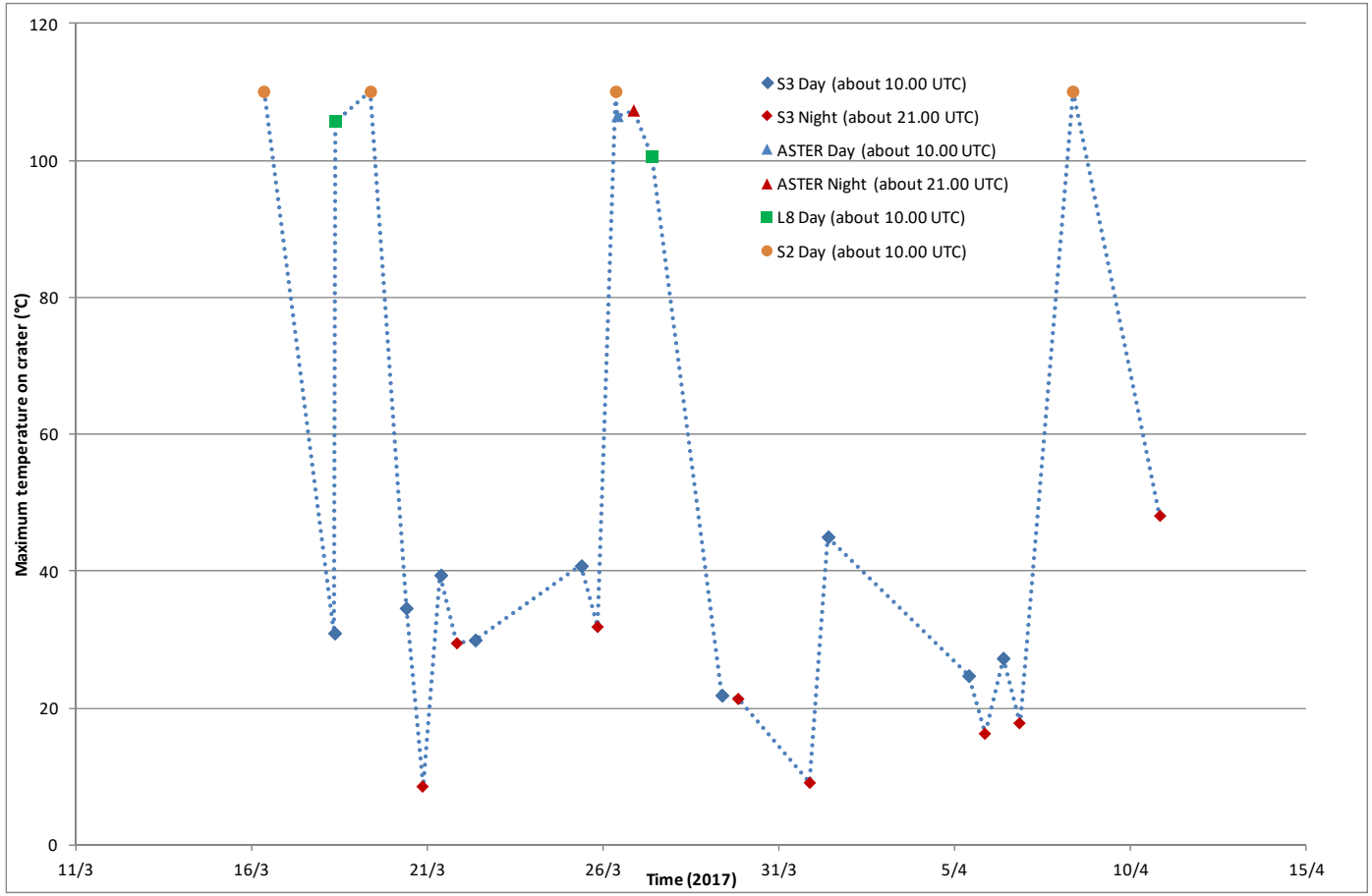
Hot Spot Map: applied to S2 data

A Procedure to define the area of an active lava flow has been developed within the GEP platform by using the approach proposed by [Murphy et al., 2016] and applied to SENTINEL 2 and S8 data (VIS-SWIR channels)

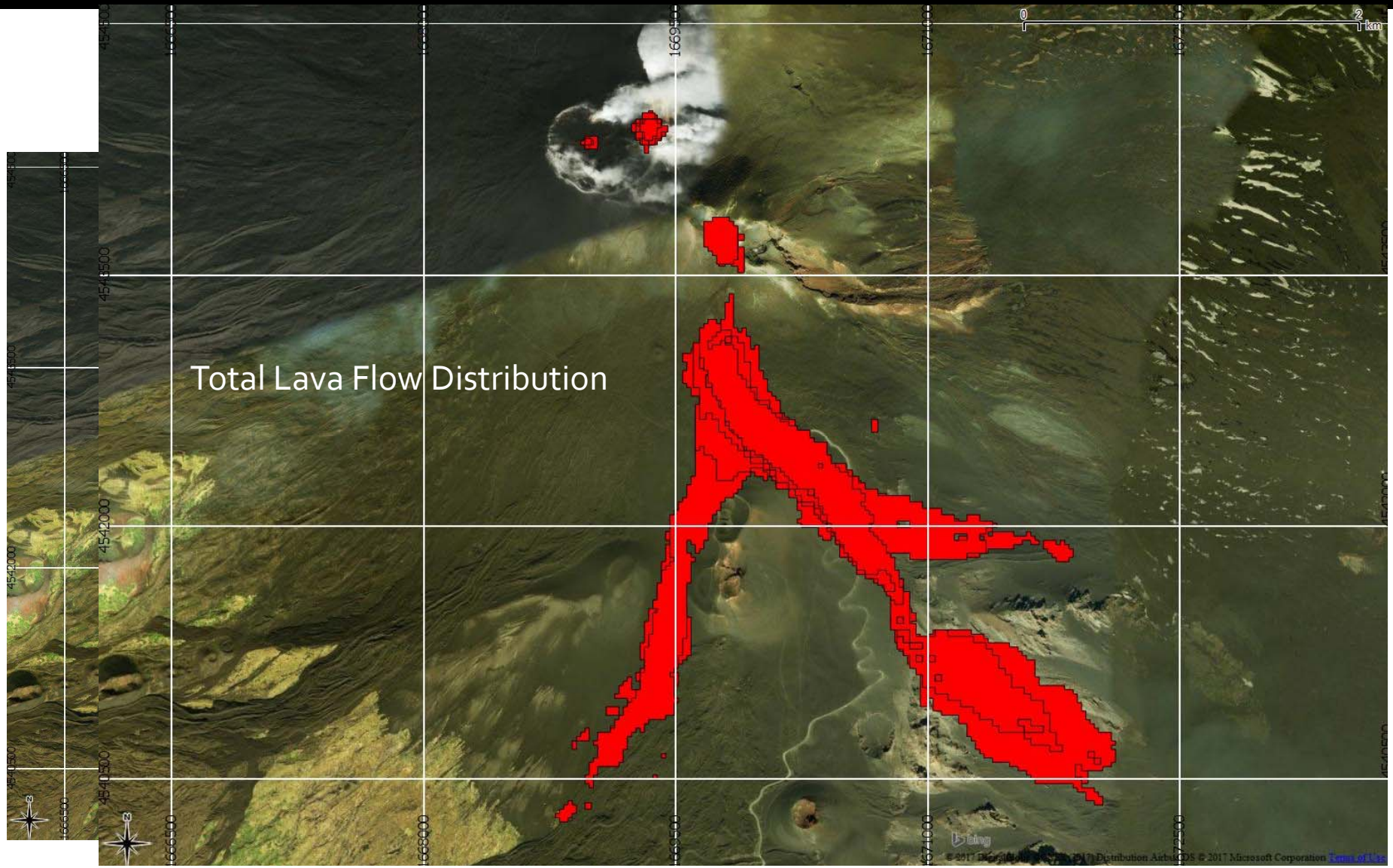
SENTINEL 2 channels
and 8A: 0.865 micron and 20 mt resolution
Band 11: 1.610 micron and 20 mt resolution
Band 12: 2.190 micron and 20 mt resolution

ETNA ERUPTION 2017

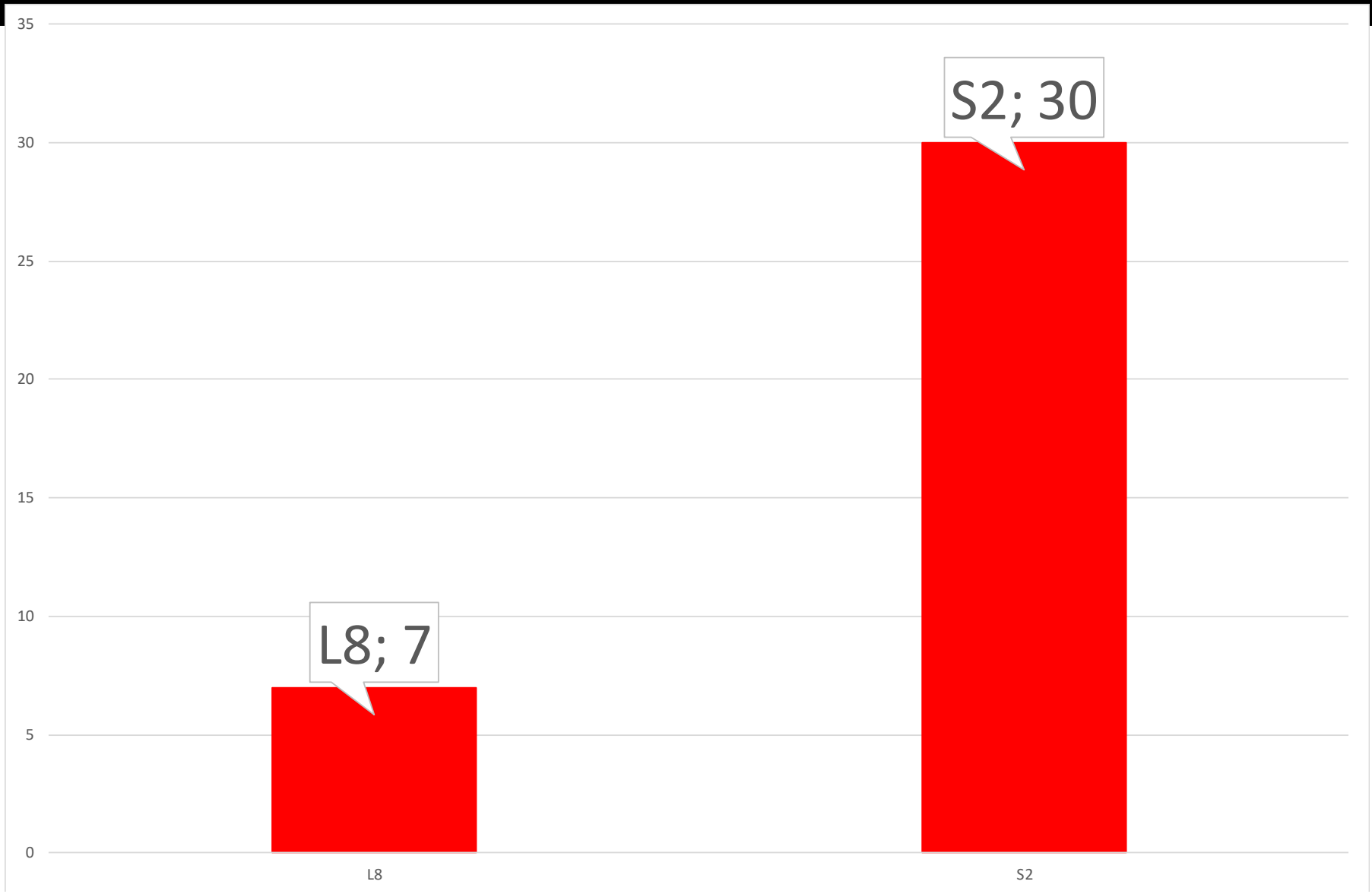
The plot below reports the number of available satellite data for approximately 1 month during last Etna eruption February-April2017



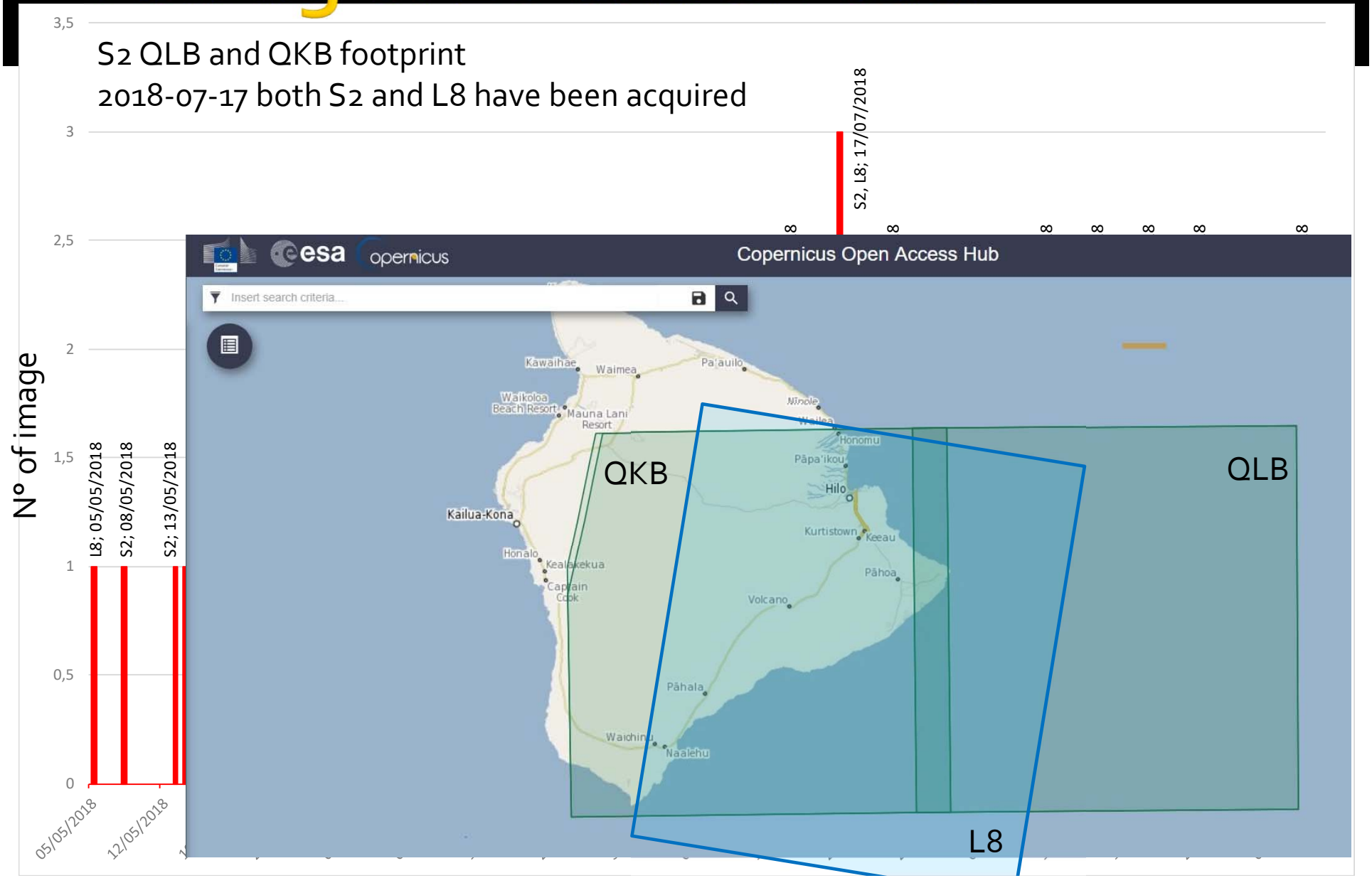
sin-Eruption Hot Spot and Lava flow detection



Kilauea Leilani 2018 eruption



Timing of L8 and S2 data



May June July August

Further development: surface temperature time series

In the fame of ESA-GEP project a time series will be produced using co-registerd EO data which will allow to digging/drilling the temperature evolution of each pixel in the scene and therefore support the studies on volcanic activity phases.

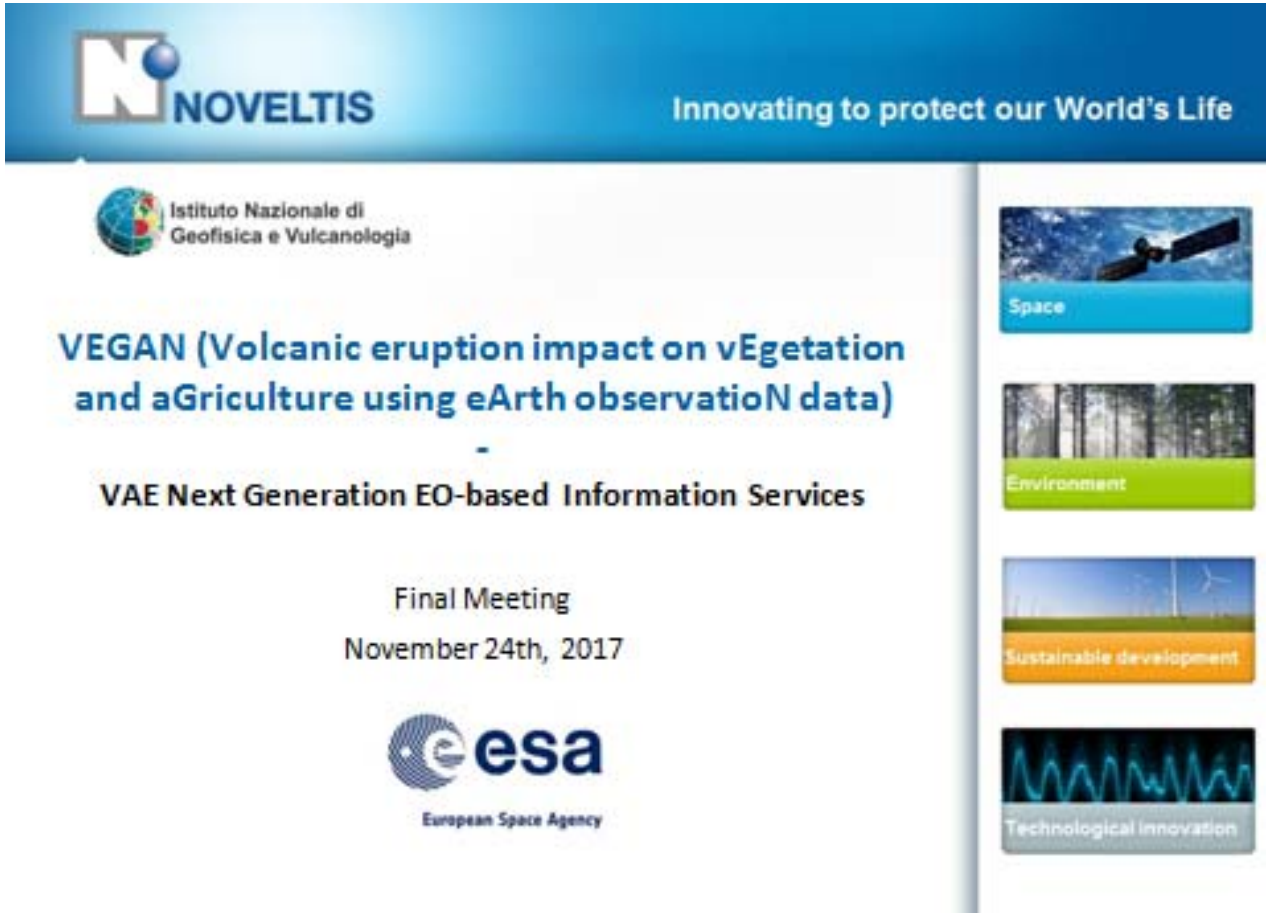
Final Considerations

- The NRT data acquired by Geostationary satellites acquiring MWIR-LWIR data offers the capability to set up a NRT operational procedure for early detection of volcanic eruption.

- free, full and open data policy adopted by NASA and ESA in the COPERNICUS program has greatly improved the development of scientific algorithms and monitoring procedures for volcanic activity at global level. The ESA GEP platform proved to be a very useful to test the rapid access to multi data and products

- The combined use of sensors with high revisit time (S3 and MSG-SEVIRI) and high spatial resolution (ASTER, L8 and S2) offers the possibility to generate an improved service detecting the beginning of an eruption and following the lava flow and the estimation of surface temperature suitable for further modeling.

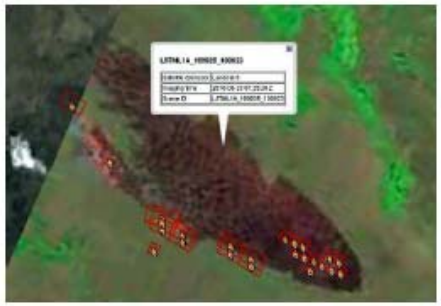
VEGAN (Volcanic eruption impact on vEgetation and aGriculture using eArth observatioN data



VEGAN project objective

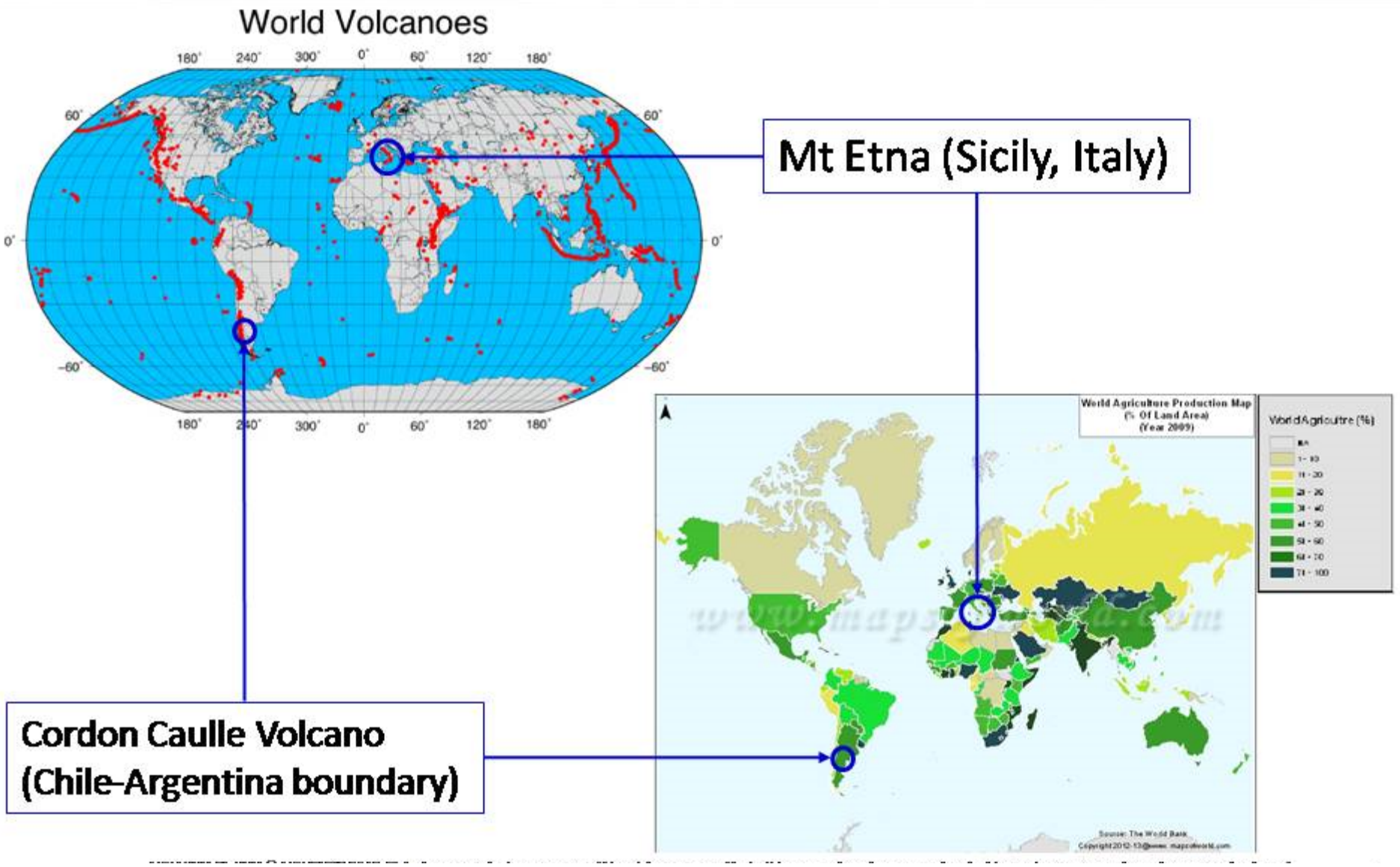
The aim of VEGAN is to develop innovative products dedicated to the assessment of the impact on vegetation and agriculture of the volcanic eruptions.

- Unique solution benefiting from the Sentinel data availability
- Taking advantage from the Geo-hazard Exploitation Platform supported by ESA
- Pre-operational test and validation with end-users
- First viability assessment for service development and furniture



Overview of the products

Product	Data source	Pre-crisis	Crisis	Post-crisis
Eruption detection	MSG-SEVIRI, GOES	✓	✓	
Ash detection	MSG-SEVIRI, MODIS		✓	
Ash dispersion model and fall out map	EROS-USGS, GFS		✓	
Hot spot map	Sentinel-2		✓	✓
Vegetation vigor map	Sentinel-2			✓


World Volcanoes
Mt Etna (Sicily, Italy)
Cordon Caulle Volcano
(Chile-Argentina boundary)
World Agriculture Production Map
(% Of Land Area)
(Year 2009)
World Agriculture (%)

VEGAN involved end-users

- **Initially involved end-users**
  - Parco del'Etna (Italy)
  - The Oficina de Riesgo Agropecuario (Argentina)
  - The Laboratorio de Estudio y Seguimiento de Volcanes Activos (Argentina)

- **Additional end-users**
  - The University of Costa Rica
  - The Volcanological and Seismological Observatory of Costa Rica
  - The Instituto Meteorologico de Costa Rica

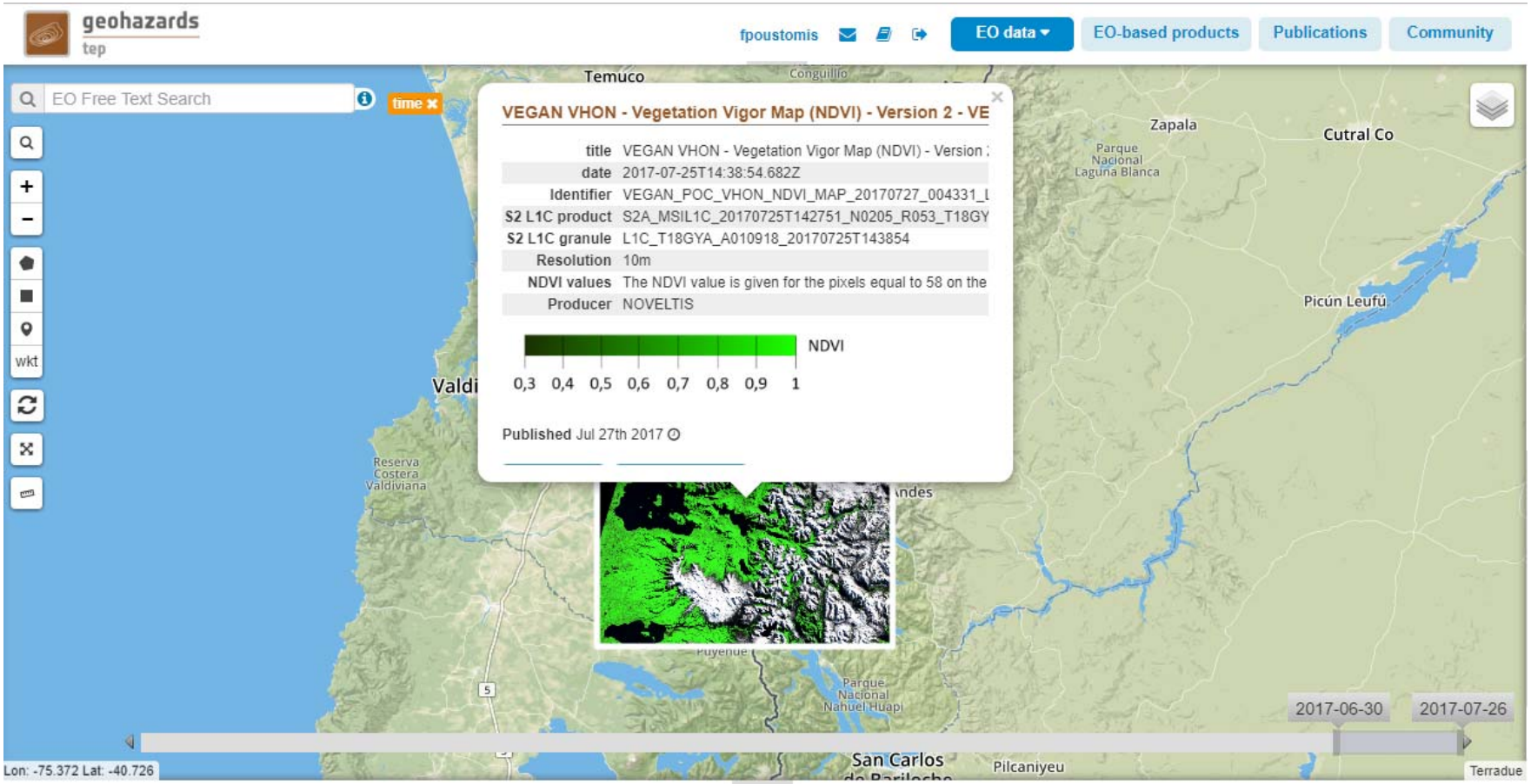
Test results of VEGAN products

All VEGAN products have been tested and validated successfully

Test ID	Test title	V0	V1	V2
TC-VEGAN-PRC-GO4RSS-001	Detection of beginning of an eruption over Etna volcano	✔	✔	✔
TC-VEGAN-PRC-GO4RSS-002	Detection of beginning of an eruption over Puyehue-Cordón Caulle volcano	✔	✔	✔
TC-VEGAN-CRI-MBTD-001	Ash detection based on MODIS BTD	✔	✔	✔
TC-VEGAN-CRI-MBTD-002	Ash detection based on MSG BTD	✔	✔	✔
TC-VEGAN-CRI-AFOM-001	Ash dispersion fall out map	✔	✔	✔
TC-VEGAN-POC-HSP-001	Application of HSP module on a large wild-fire	✔	✔	✔
TC-VEGAN-POC-HSP-002	Application of HSP module on a non-burning area	✔	✔	✔
TC-VEGAN-POC-HSP-003	Application of the version 2 of HSP module on a volcano after an eruption			✔
TC-VEGAN-POC-VHON-001	Application of VHON module on a scene containing vegetation and other features	✔	✔	✔
TC-VEGAN-POC-VHON-002	Application of VHON module on an AOI with an agricultural field	✔	✔	✔
TC-VEGAN-POC-VHON-003	Application of the version 2 of VHON module on a scene containing vegetation and other features			✔
TC-VEGAN-POC-VHOF-001	Application of VHOF module on time series dataset for an AOI with a scene containing vegetation and other features		✔	✔

VEGAN implementation on GEP

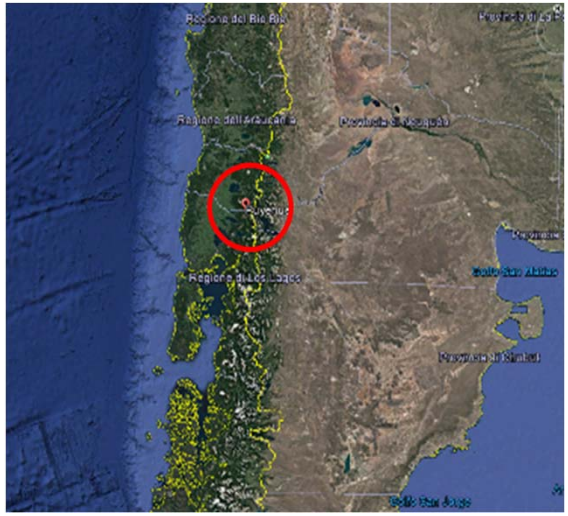
- A lot of effort was invested by NOVELTIS to ensure this implementation.



End user's requirements

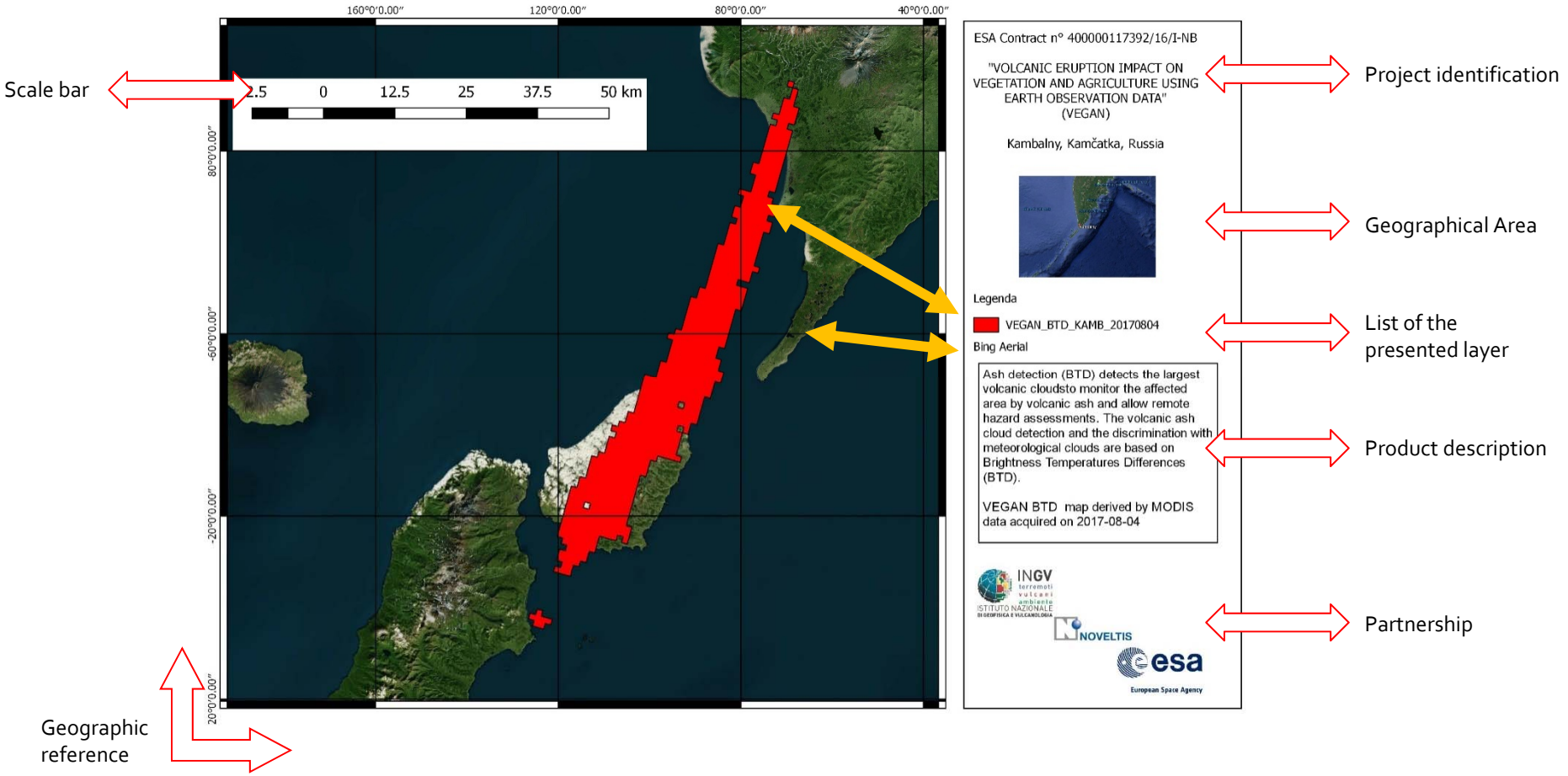
Use case: Puyeue-Cordon Caulle

PUYEUE-CORDON CAULLE Area of Interest	
Name:	Región del volcán Cordón Caulle
Type:	Considering the vegetation cover, in Chubut and Río Negro predominate steppes, "arbustivas" and "arbustivo-graminosas". On the western side of both provinces, there are a wooded zone and other zone with steppes, "arbustiva" and "graminosa-arbustiva". To the east of Río Negro province, we can find predominantly "estepa arbustiva de monte" and "matorral de monte". For this reason the provinces involved are principally engaged in the agricultural sector, extensive livestock type.
Description:	The areas has been affected by the 2011 eruption. The provinces of "Río Negro", "Neuquén" and "Chubut" in Argentina were the most affected, with much of the accumulated ash covered between 0,5 and 5 cm thick area.
Period to be studied	June 2011



Pilot service demonstration: Interaction with end-users

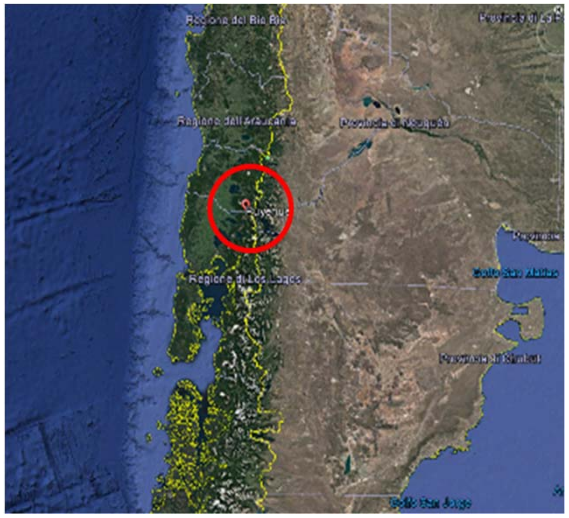
- VEGAN product presentation



Use case: Puyeue-Cordon Caulle

- **Involved end-user**: The Oficina de Riesgo Agropecuario
  The Laboratorio de Estudio y Seguimiento de Volcanes Activos

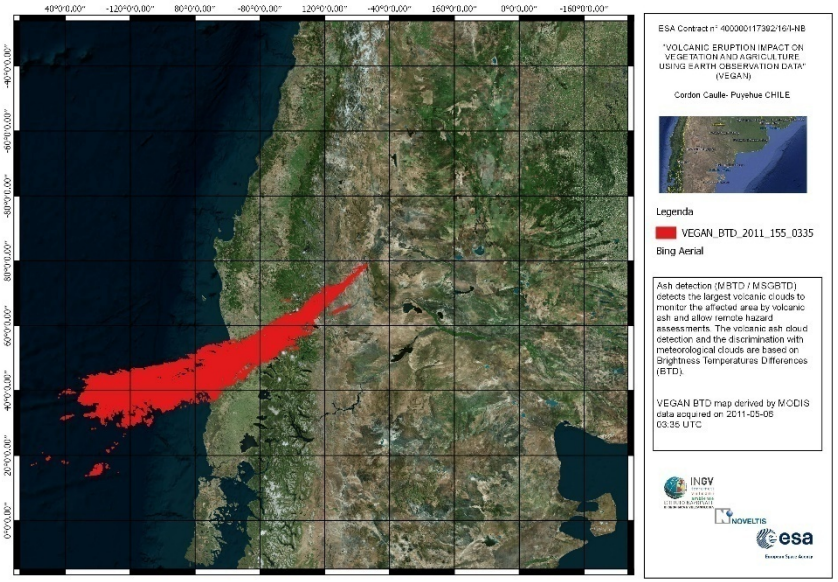
- **Location**:



- **Studied event**: eruption of June 2011

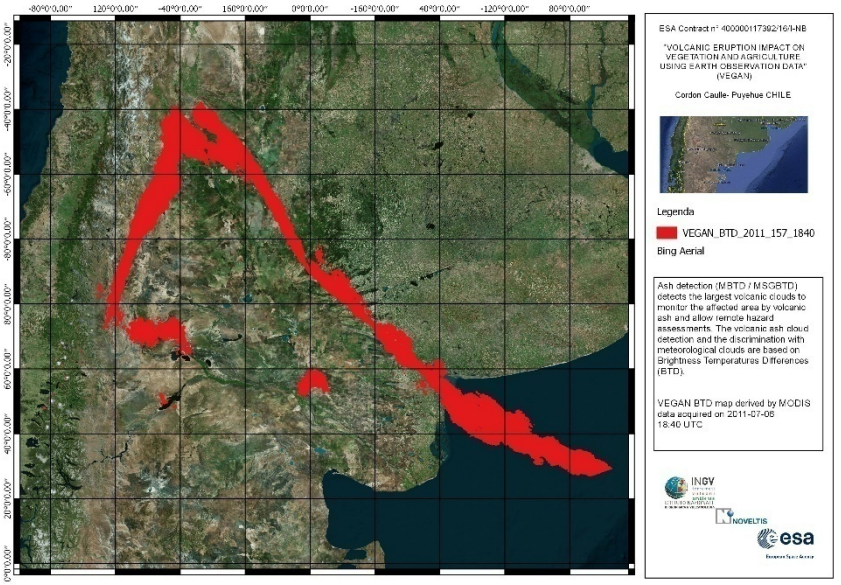
Use case: Puyeue-Cordon Caulle

- **Generated Ash detection in the thermal infrared products**



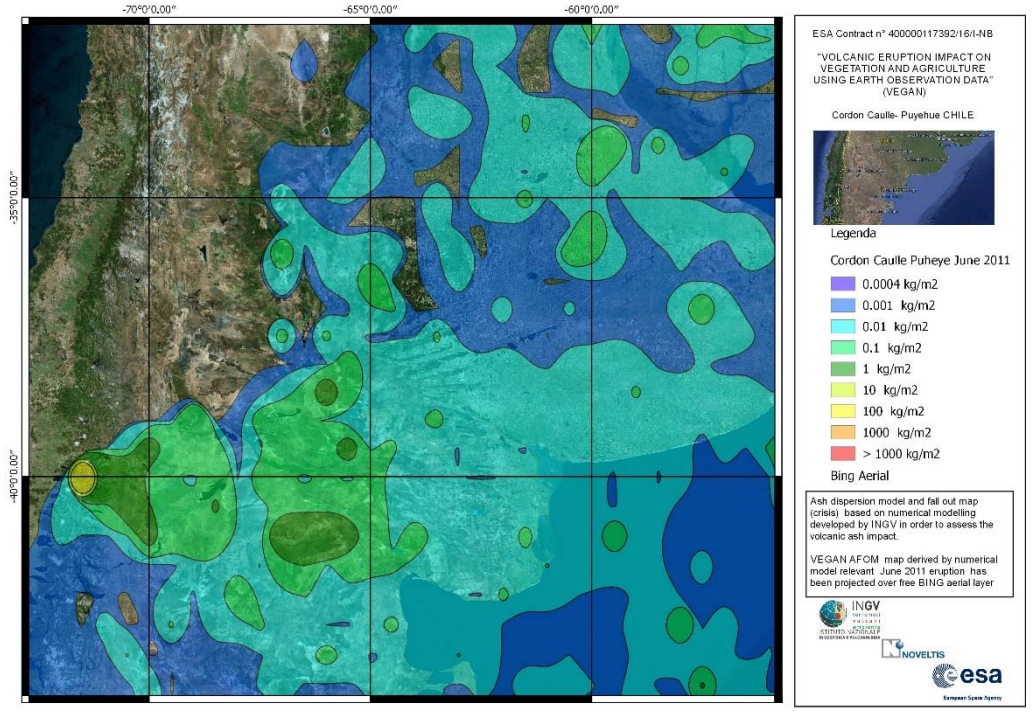
BTD map, June 5th 2011,
03:35 UTC

BTD map, June 7th 2011,
18:40 UTC



Use case: Puyeue-Cordon Caulle

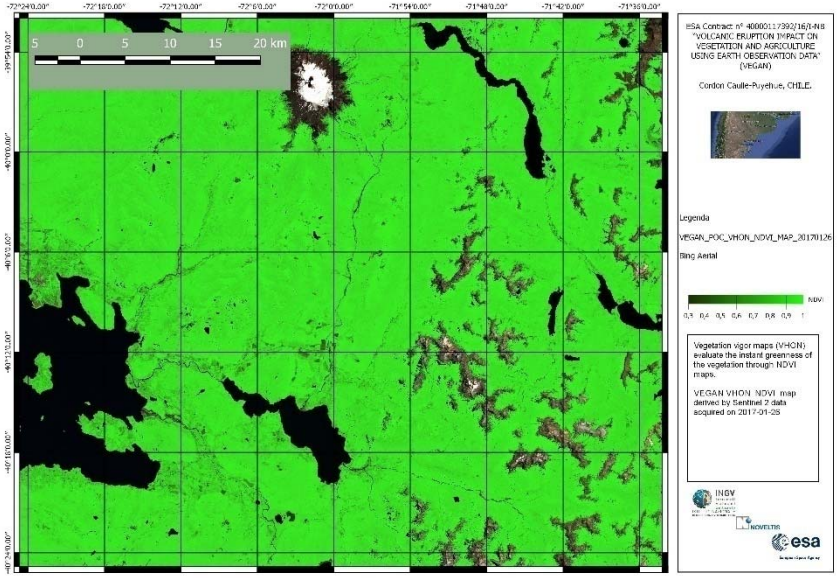
- **Generated Ash fall out map products**



AFOM, June 2011

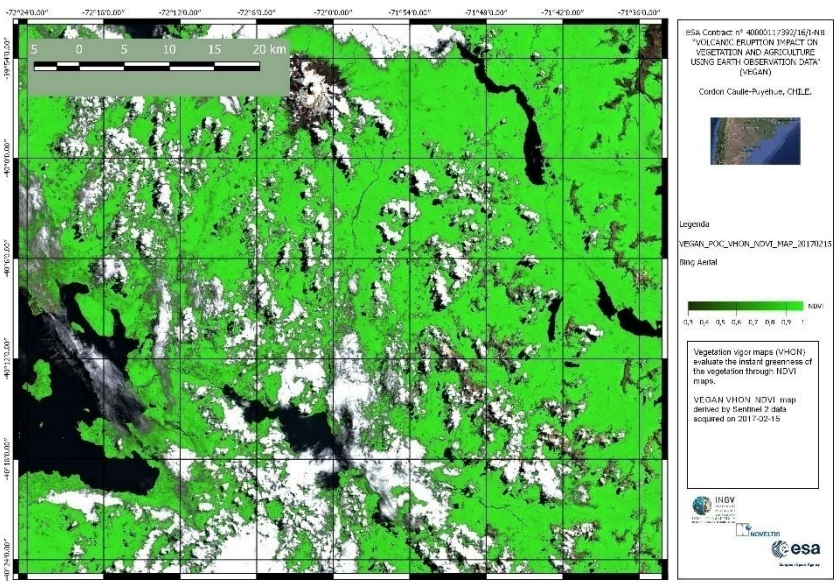
Use case: Puyeue-Cordon Caulle

- **Generated Vegetation vigor map products**



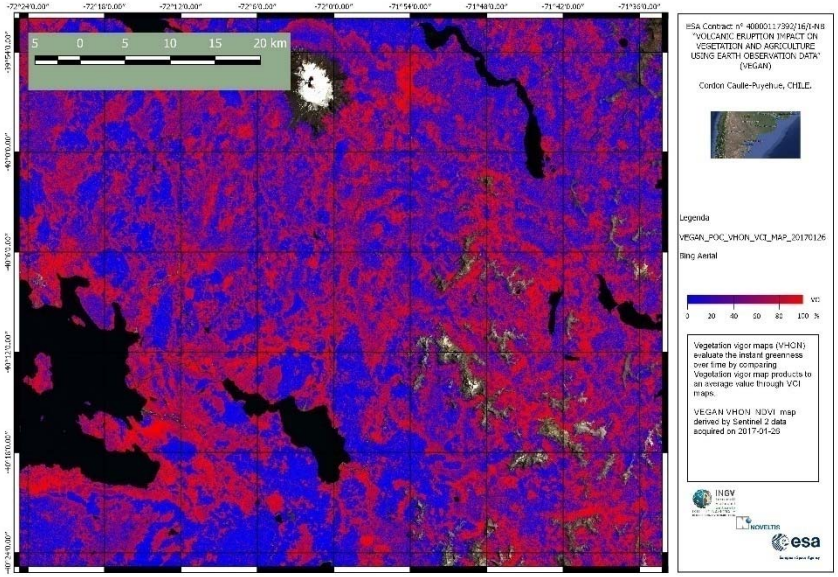
NDVI map, January 26th 2017

NDVI map, February 25th 2017



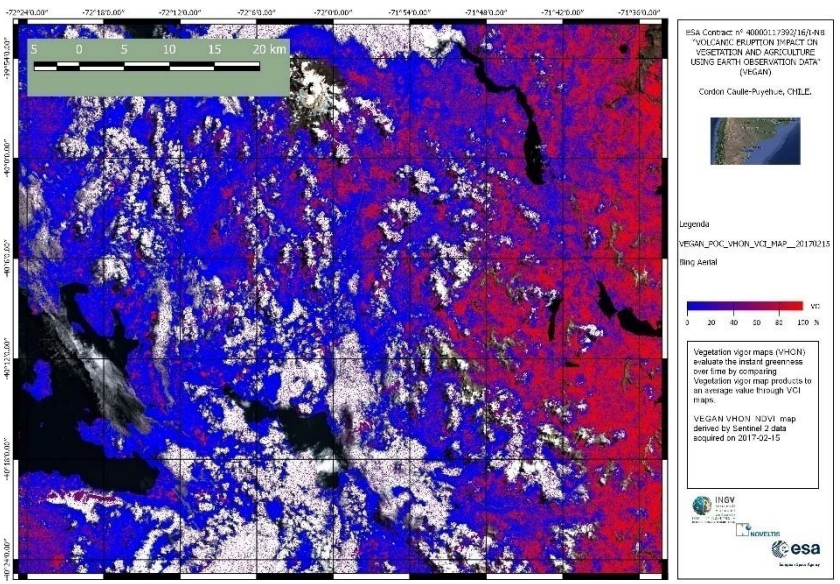
Use case: Puyeue-Cordon Caulle

- **Generated Vegetation health monitoring products**



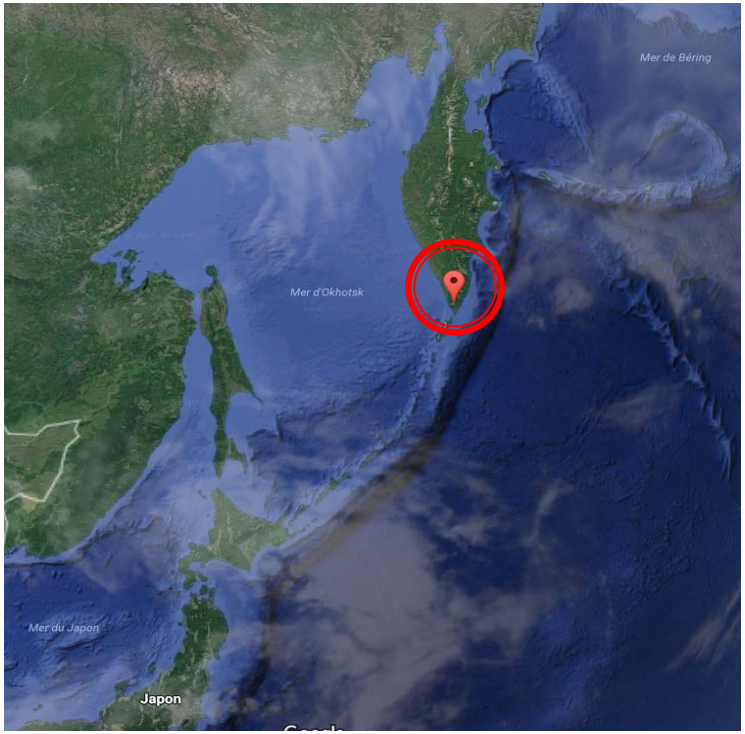
VCI map, January 26th 2017

VCI map, February 25th 2017



Use case: Kambalny

- **Location**:



- **Studied event**: eruption of March 2017

Use case: Kambalny (blind test)

TIME TO DECIDE ERUPTIVE PARAMETERS: **30 min**.

Meteo data: Air Resource Laboratory, GDAS Global, from 25/03/2017 (00.00 UTC) to 28/03/2017 (21.00 UTC). Data every 3 h.

TIME TO DOWNLOAD AND TO PRE-PROCESS METEO DATA: **1 h**

TIME TO CODE MODIFICATIONS (una tantum): **3 h**
Simulation data:
- ash emission start 25/03/2017 h. 01.00 UTC
- ash emission end 28/03/2017 h. 21.00 UTC
- end of simulation 28/03/2017 h. 21.00 UTC
- calculation grid resolution 0.5°
- calculation domain extent 25/55° lat, -150/+150° long
- average particles density 2000 kg/m3
- shape factor 0.6
- MFR 3.16x10^5 kg/s

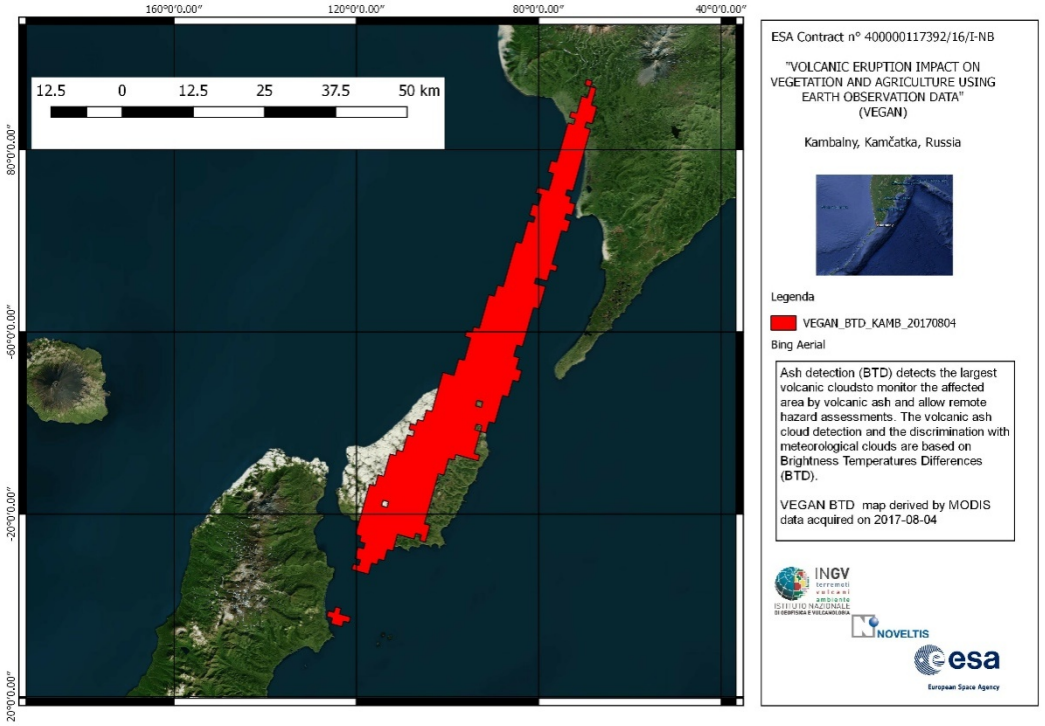
About 5 and ½ hour

TOTAL TIME (SIMULATION AND POST-PROCESSING): **15 min**

TIME TO WRITE THE REPORT: **30 min**

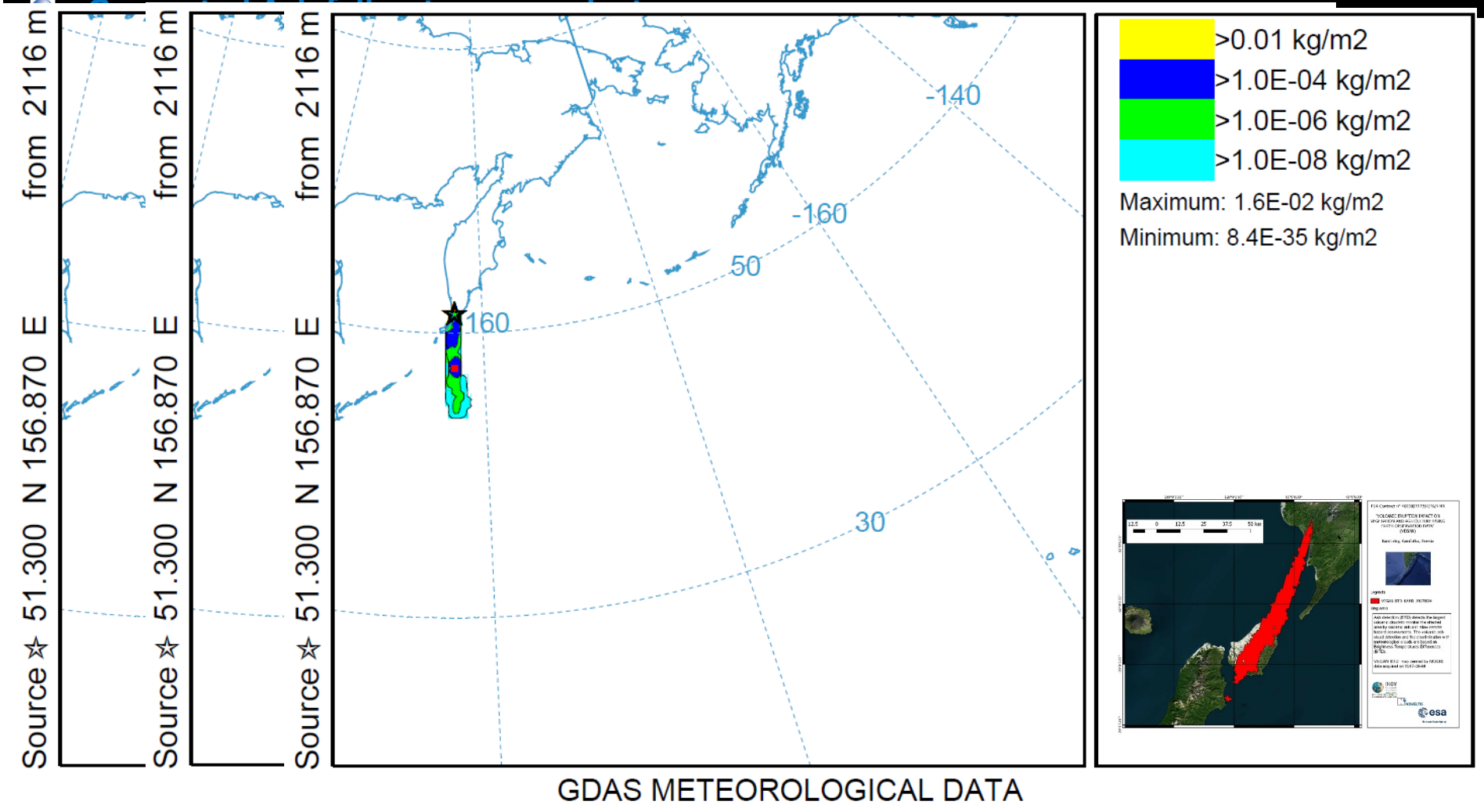
Use case: Kambalny

- **Generated Ash detection in the thermal infrared products**



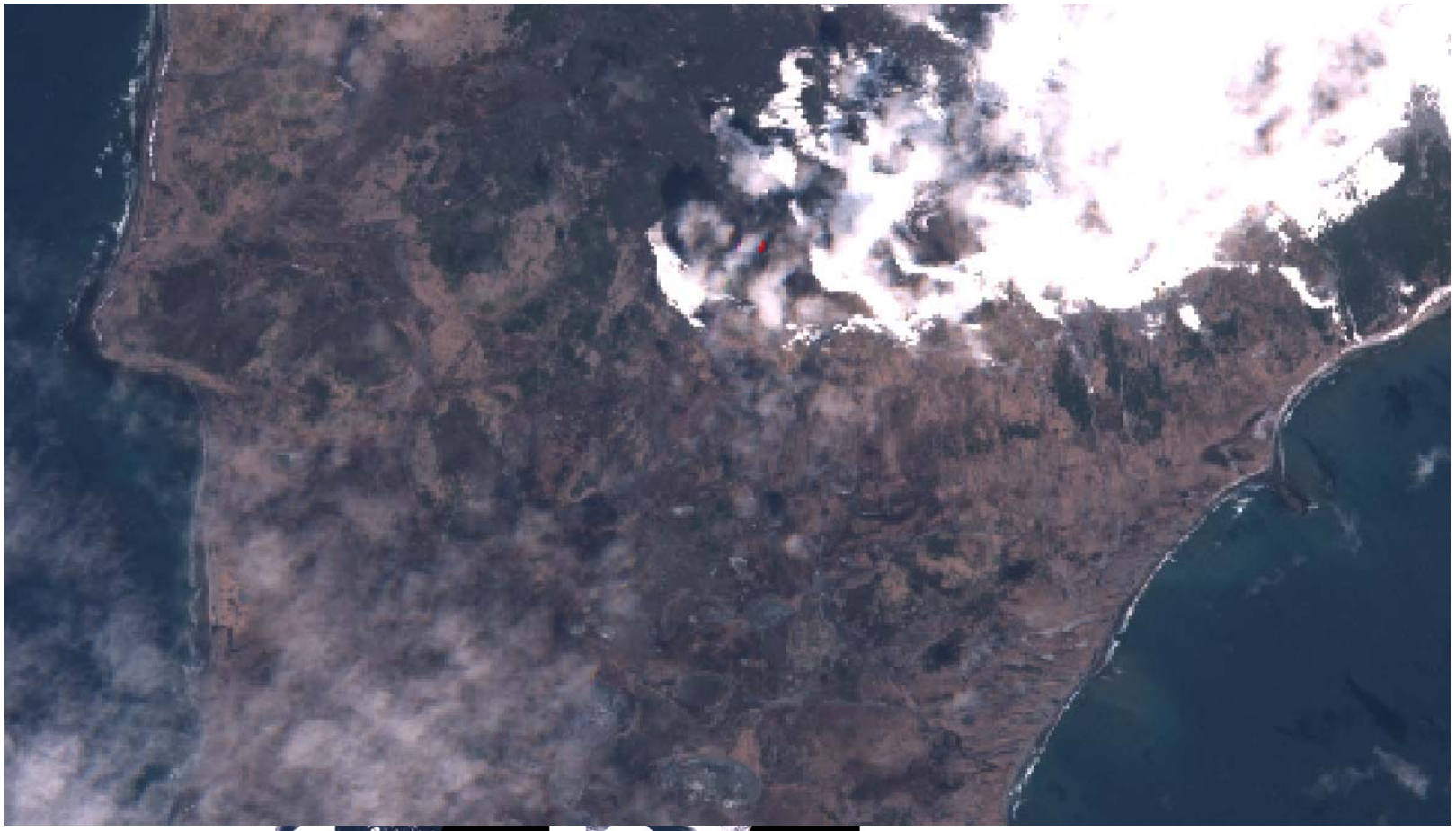
BTD map, April 8th 2017

Use case: Kambalny



Use case: Kambalny

- Generated Hot spot map products



Hot spot maps, from February to April 2017

Costa Rica User community

with local and national incidence and that transcend their work in the fields of teaching and social action.
It is very important to note the UCR were not involved by the project beginning and its contribution have to be considered as kindly offered. Prof. Jorge Andres Diaz has been very kind and helpful in evaluating, both scientifically and technically, the products generated by the VEGAN project. We want to thank him for the commitment he has supported this project.

- Website: https://www.ucr.ac.cr/
- Manager of the UCR : : Dr. Henning Jensen Pennington
- Tel (+506) 2511-1250
- E-mail: buzon.rectoria@ucr.ac.cr
- Sede "Rodrigo Facio Brenes" Montes de Oca, San José Costa Rica.

The Volcanological and Seismological Observatory of Costa Rica, is an interdisciplinary research institute of the National University. Its mission is seismic and volcanic monitoring to document, analyze and interpret these processes and disseminate the derived knowledge to contribute to the prevention of risks and mitigation of the disasters that these phenomena may generate

- Website: http://www.ovsicori.una.ac.cr/
- Manager of the OVSICORI: : Dott Montero Cascante Carlos
- Tel (506)2562 4001 (506)2261 0611 - (506)2261 0781
- E-mail: ovsicori@una.cr
- Postal address 2386-3000 Heredia, Costa Rica.

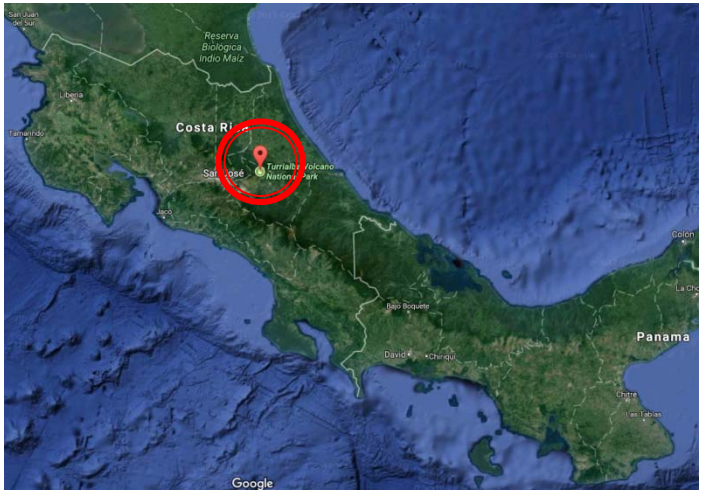
The IMN (for its acronym in Spanish) is an institution affiliated to the Ministry of Environment and Energy (MINAE), is a scientific body that is in charge of the coordination of all meteorological and climatological activities in the country. It maintains a systematic monitoring of the weather to provide support for the safety of air navigation in the country, for the prevention of hydrometeorological disasters and contribute to the adverse effects of variability and climate change.

- Website: https://www.imn.ac.cr/en/inicio
- Manager of the IMN: -----
- Tel. T: (506)2222-5616 F: 2223-1837
- E-mail: -----
- Postal address San José, Costa Rica Barrio Aranjuez, Avenida 9 y Calle 17.

Use case: Turrialba

- **Involved end-users**: The University of Costa Rica
  The Volcanological and Seismological Observatory of Costa Rica
  The Instituto Meteorologico de Costa Rica

- **Location**:

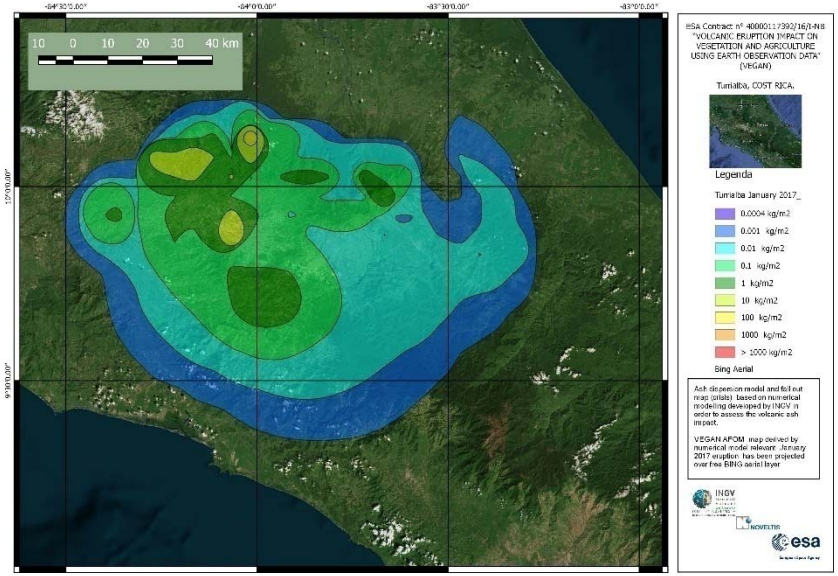


- **Studied event**: eruptions of January and March 2017

CEOS meeting, Spetember 5-6 2018, Napoli

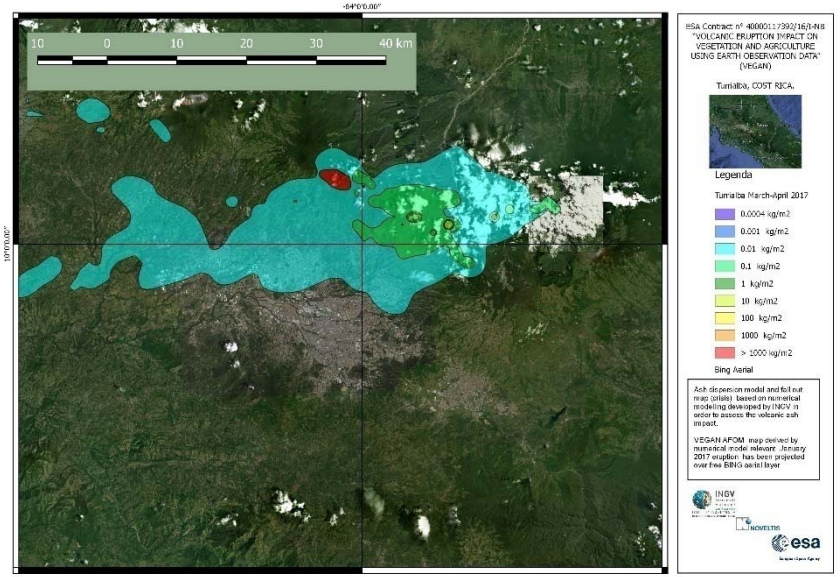
Use case: Turrialba

- **Generated Ash fall out map products**



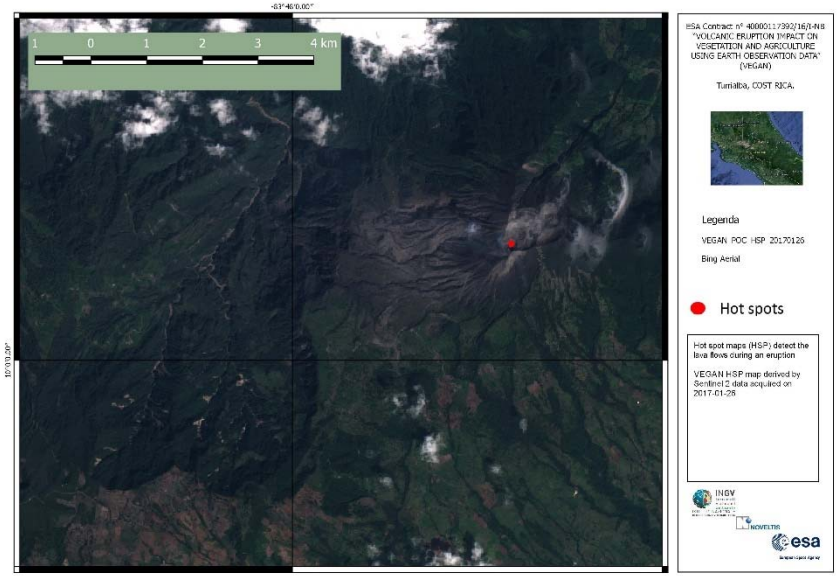
AFOM, January 2017

AFOM, March/April 2017



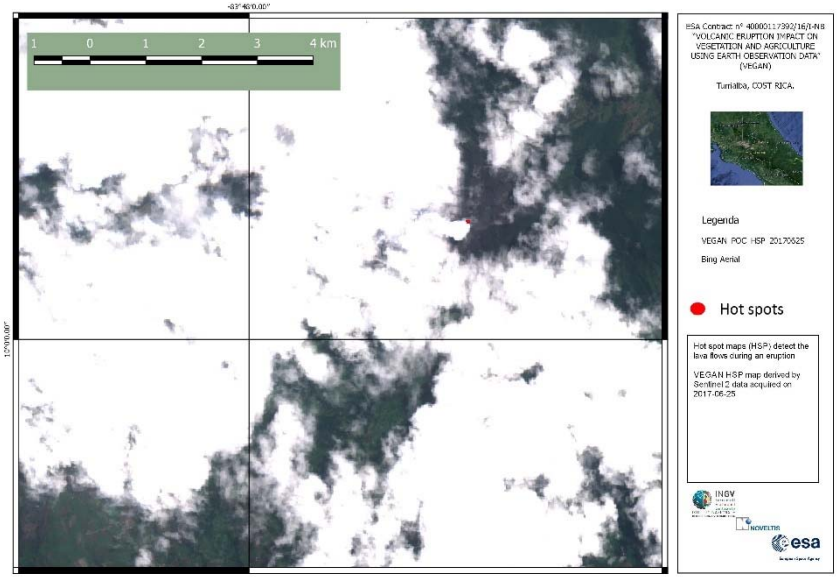
Use case: Turrialba

- Generated Hot spot map products



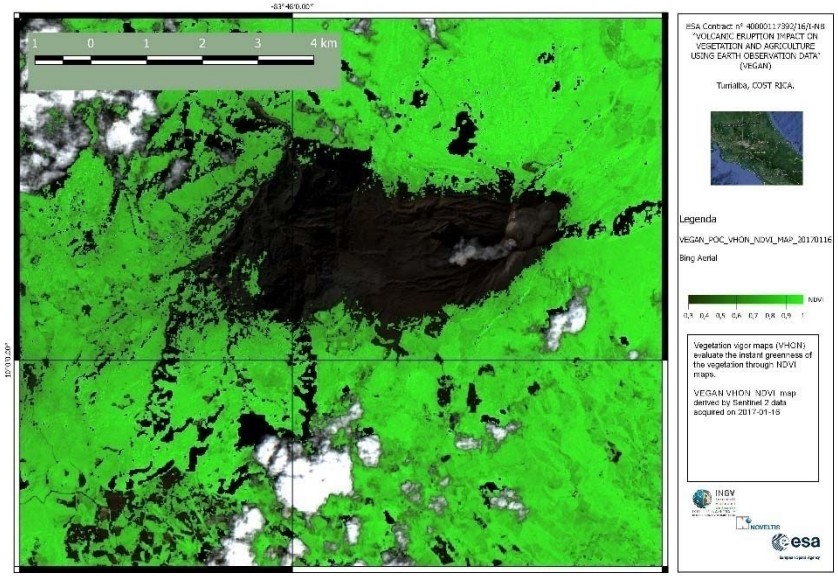
Hot spot map, January 26th 2017

Hot spot map, June 25th 2017



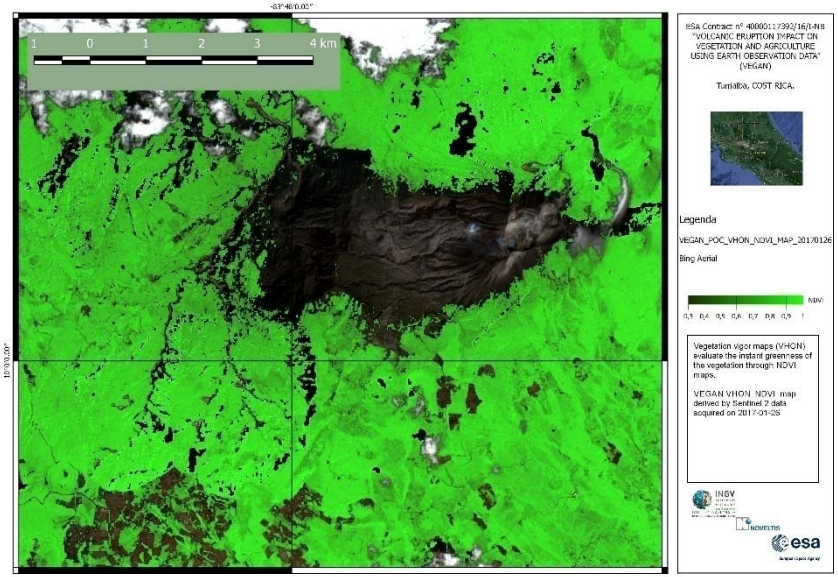
Use case: Turrialba

- **Generated Vegetation vigor map products**



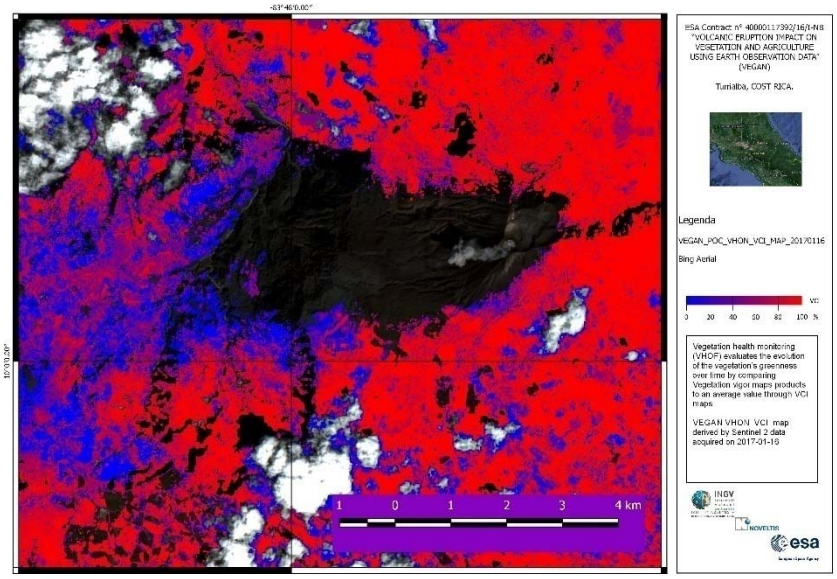
NDVI map, January 16th 2017

NDVI map, January 26th 2017



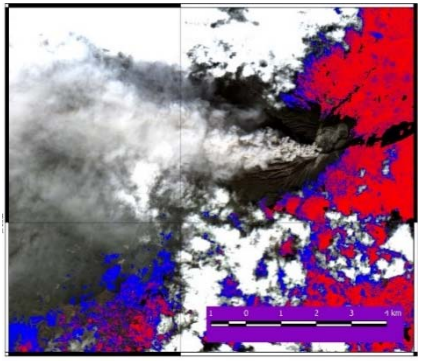
Use case: Turrialba

- Generated Vegetation health monitoring products

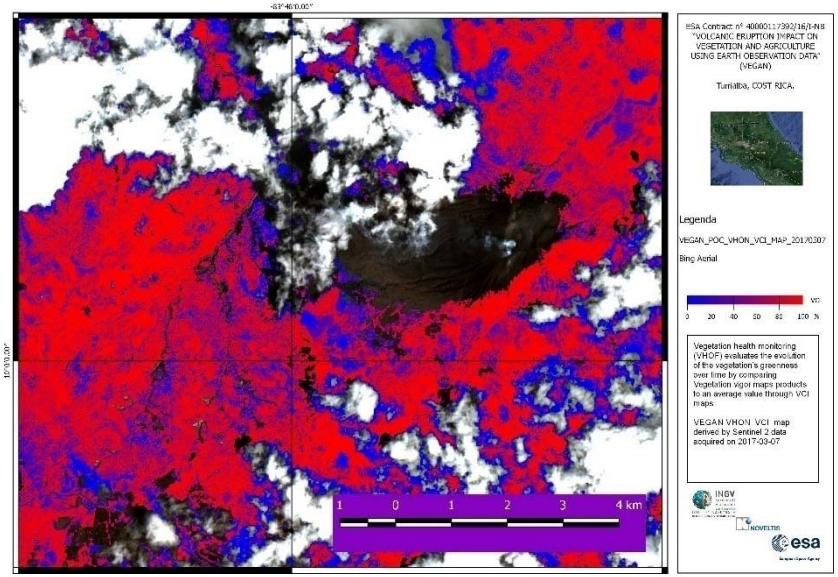


VCI map, January 16th 2017

Eruption of January 6th 2017

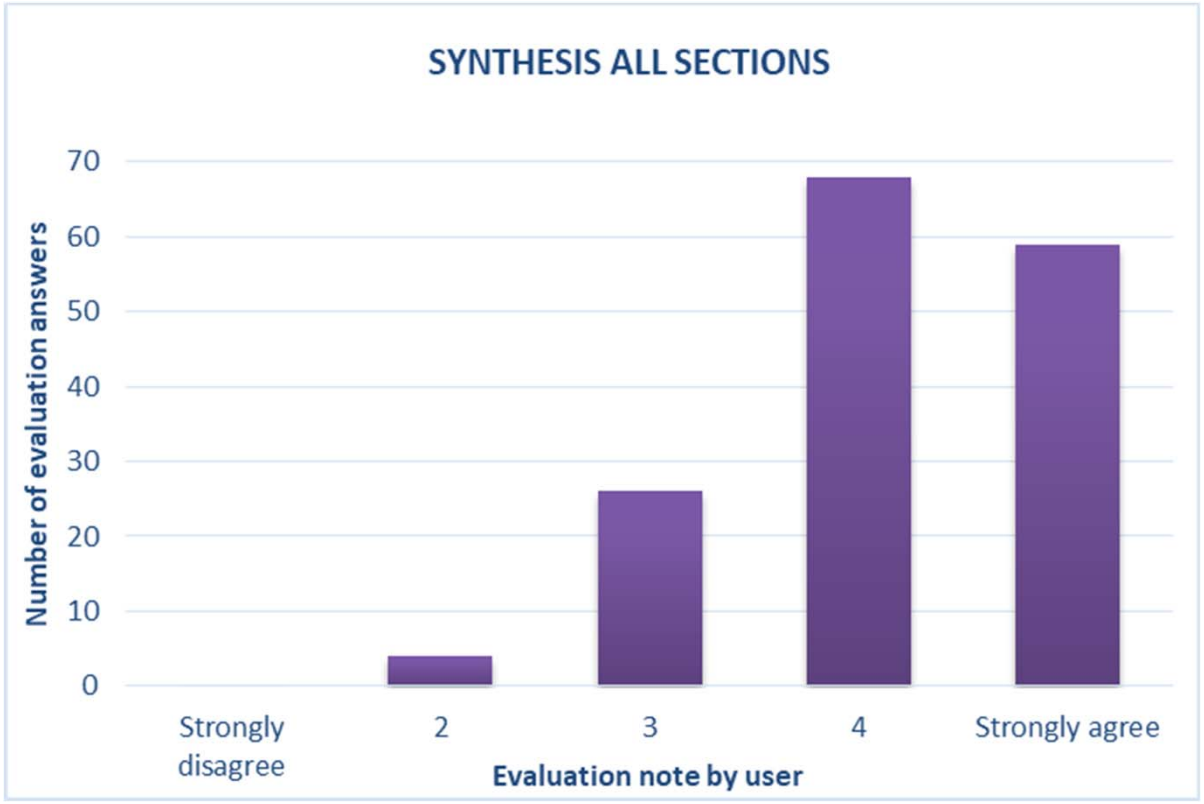


VCI map, March 7th 2017



General synthesis from user's perspective

- Global satisfation level



General synthesis from user's perspective

- General evaluation

Positive points	Points to be enhanced
Good utility at management level	Users would be more confident if VEGAN includes in-situ data in addition to satellite data
Good usability	Delivery frequency not fully sufficient for crisis products (limitation due to satellite data availability)
Easy-to-use	
It improves previous technologies already tried	
User friendliness	

General synthesis from producer's perspective

Product	Pre-crisis	Crisis	Post-crisis	Comments / Difficulties
Eruption detection	✔			Real-time capacity with SEVIRI data Some limitations concerning the real time with GOES data
Ash detection in the thermal infrared (TIR) spectral range	(✔)	✔		Some distortions with off-nadir acquisitions Negligible quantity of emitted ash are difficult to detect Presence of water vapour can mask the presence of ash
Ash dispersion model and fall out map		✔		Limitation of this procedure are due to the meteo data
Hot spot maps		(✔)	✔	Some limitations in case of clouds around the volcano
Vegetation vigor maps			✔	Some limitations in case of clouds around the volcano Sen2cor classification not correct for smoggy areas or opaque clouds Sen2cor vegetation classification removes vegetation pixel with very poor vigor
Vegetation health monitoring	✔		✔	Longer Sentinel-2 time series are required Biased in case of close eruptions over the same volcano Gas emissions cause also vegetation death

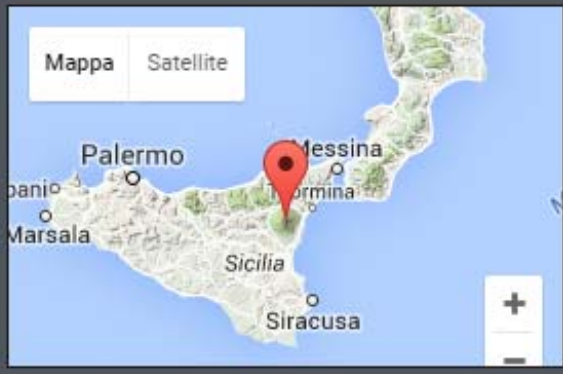
knowledgements

We would like to thank:

- **ESA** for the opportunity to contribute to the GEP and VEGAN project
- **NASA-JPL** for the very fruitful and long collaboration and for having continuously supported INGV by providing ASTER data to study and monitor Italian active volcanoes
- **USGS** for the active collaboration on LANDSAT8 data providing night time data and for the participation to the calibration activities on Italian Volcanoes.

THANK YOU

Test Sites: Mt Etna, Sicily (Italy)

Mt Etna is the largest active volcano in Europe with a diameter of 40x40 kmq and elevation of about 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.

Country	Italy
Volcanic Region	Mediterranean and Western Asia
Primary Volcano Type	Stratovolcano(es)
Last Known Eruption	2016 CE
Latitude	37.734°N
Longitude	15.004°E
Summit Elevation	3330 m / 10922 ft
Volcano Number	211060