LAV@HAZARD: a satellite-driven modeling strategy for quantifying lava flow hazards

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INGV – CT, Laboratory of Technologies for Volcanology (TechnoLab)

SOTTOTITOLO

Thematic area: Earth Observation

VOLCANIC HAZARD MONITORING FROM SPACE

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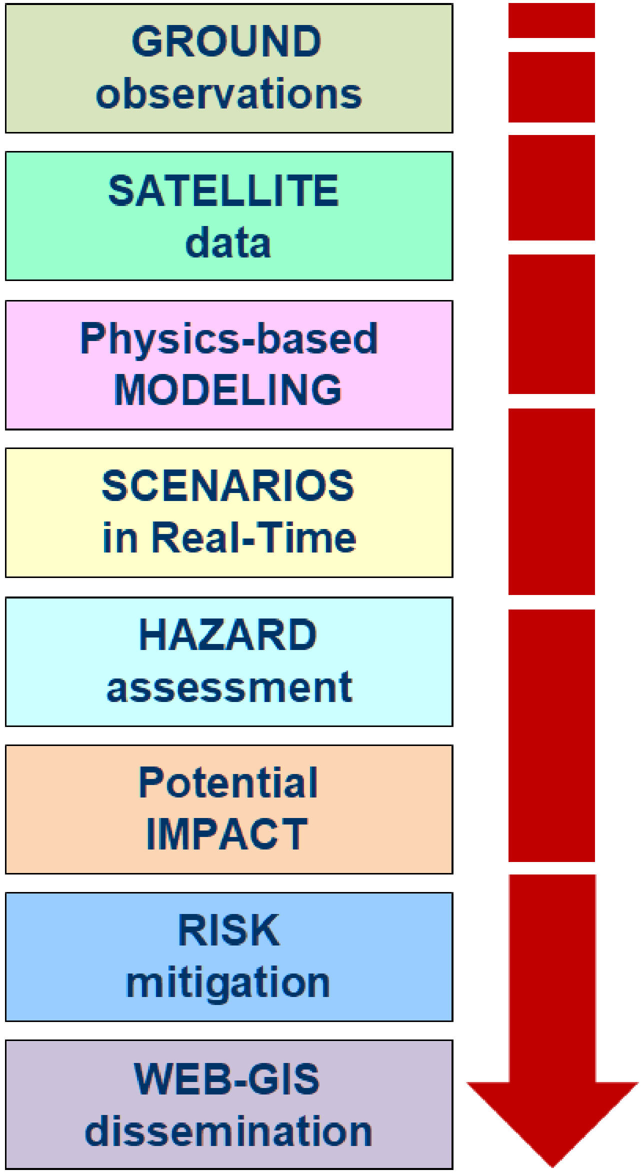
• SCIENTIFIC RATIONALE



Hazard response chain

Quantifying lava flow hazards by combining field observations, satellite data and numerical modeling has immediate applications to the real time monitoring of effusive eruptions.

By monitoring, we mean here both following the manifestations of the eruption once it has started, as well as forecasting the areas potentially threatened by lava in an effusive scenario.

Our strategy, based essentially on the combination of the HOTSAT system with the MAGFLOW model, now represents the first operational monitoring system that allows us to give during an eruption:

(i) the current state of the effusive activity

(ii) the probable evolution of the lava flow field

(iii) the potential impact of lava flows

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• OBSERVATIONAL INFRASTRUCTURE

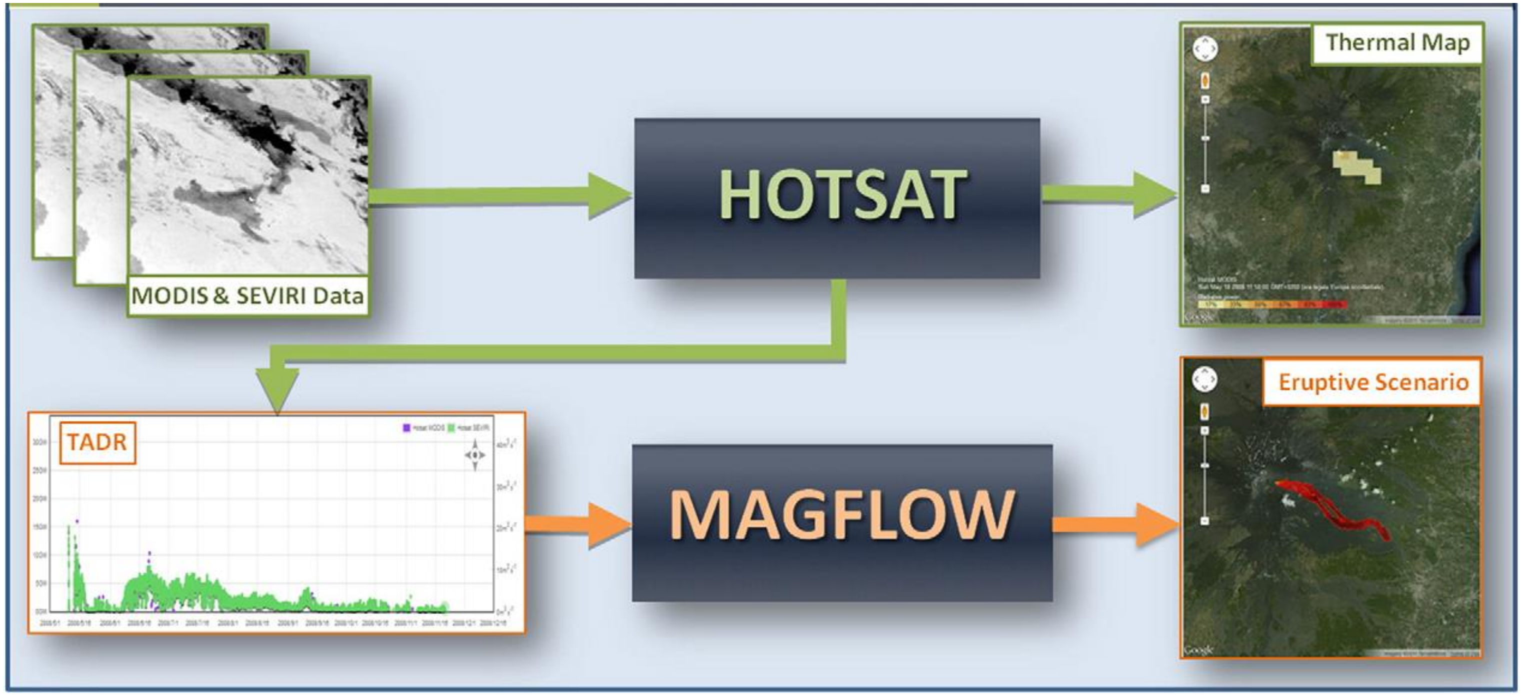
Satellite-driven modeling strategy

The TechnoLab of the INGV-CT has developed a satellite-driven modeling strategy for quantifying lava flow hazards during an ongoing eruption. This strategy involves three main steps:

(i) hotspot detection

(ii) effusion rate estimation

(iii) lava flow forecasting



For these tasks, we use two tools:
- the **HOTSAT** system for hot-spot detection that works with satellite thermal infrared data and

- the **MAGFLOW** model for lava flow simulations that takes into account how the effusion rate changes during eruptions

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• OBSERVATIONAL INFRASTRUCTURE

MSG-SEVIRI

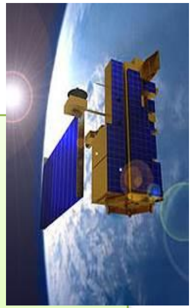
Geostationary Orbit

Spatial resolution: VIS,IR=**3 km**

Temporal resolution: **15 minutes**

HOTSAT

EOS-MODIS

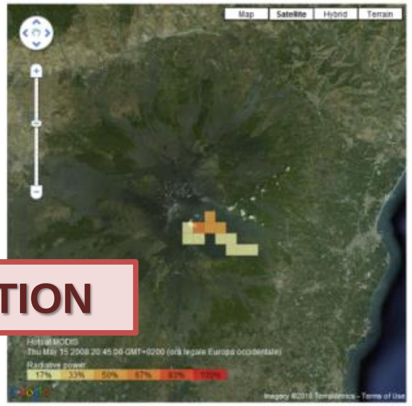


Polar Orbit

Spatial resolution: 250 m to **1 km**

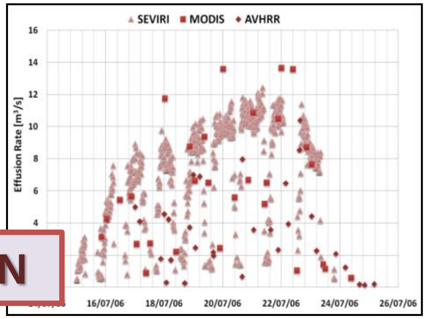
Temporal resolution: **6-12 hours**

1. CLOUD INDEX



2. HOTSPOT DETECTION

3. RADIANT HEAT FLUX



4. TADR ESTIMATION

HOTSAT
Satellite data processing system

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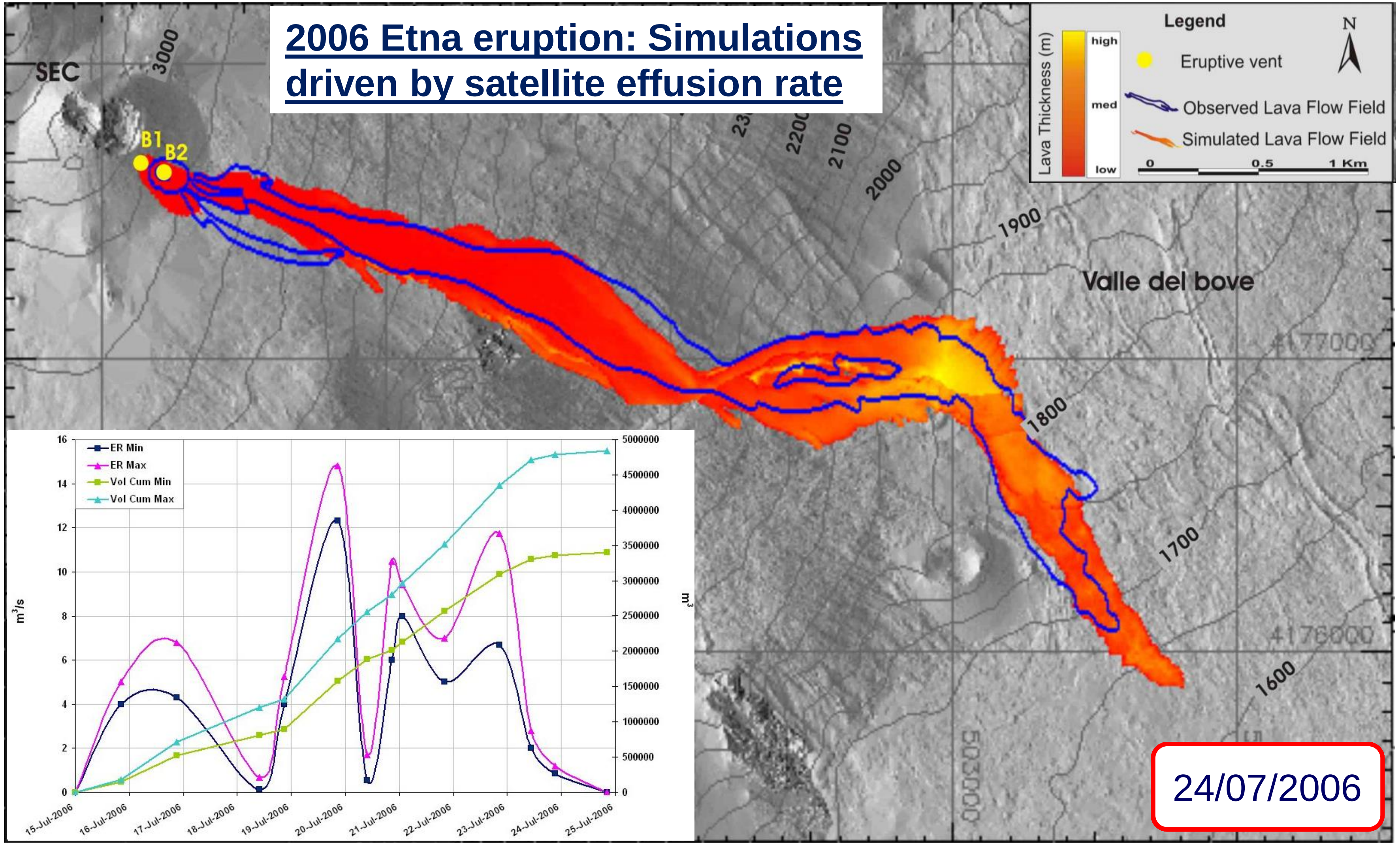
• MAGFLOW MODEL



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• INFRASTRUCTURE FOR DATA PROCESSING

N E A R   R E A L   T I M E

Codes implemented on Graphic Processing Units (GPUs)

GPUs offer very high performances in parallel computing. The porting of MAGFLOW and HOTSAT from the original serial codes to the parallel computational platforms was accomplished using CUDA and OpenCL programming languages, providing ways to access the GPU capabilities.

SPEED-UP – Run times of OpenCL implementations of HOTSAT in different devices (times in ms)

Kernel	Beignet/ Haswell GT2 Mobile	NVIDIA/ GeForce GT 750M	Intel/i7-4712HQ@2.3 GHz
compute_background_radiance	0.13	0.0569	0.243
compute_hotspot_data	0.016	0.0133	0.068
compute_radiative_power	0.008	0.0091	0.078
compute_Tdiff_variance	1.943	0.3647	1.812
compute_thresholds	2.299	0.6513	1.541
find_potential_hotspots	0.007	0.0108	0.065
prepare	1.301	0.2771	3.376

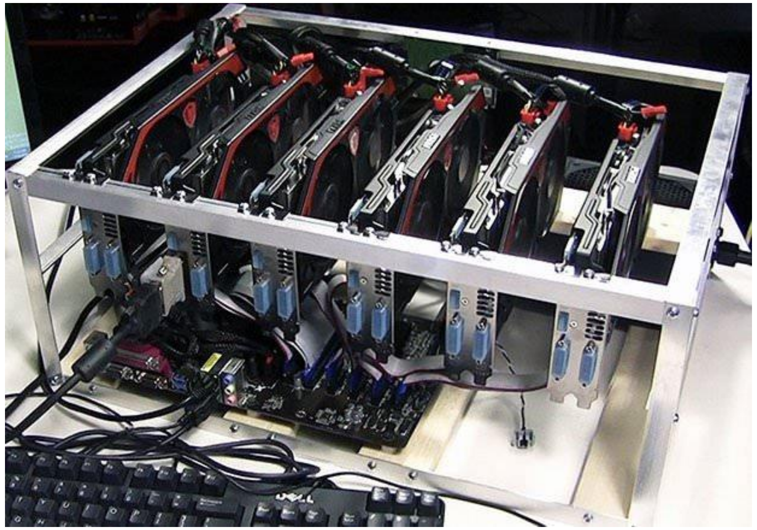
BENEFIT Running MAGFLOW on GPUs provides a simulation spanning several days of eruption in a few minutes.

Event duration	Running time
7 days	2-3 minutes
1 month	10 - 15 minutes

• INFRASTRUCTURE FOR DATA MANAGEMENT

Data storage: 10 TB/year

Data processing: cluster with 12 GPUs
4 x NVIDIA TITAN X
1 x VGA GTX TITAN
4 x NVIDIA GEFORCE GTX 1080Ti
1 x NVIDIA GEFORCE GTX 1050Ti
2 X NVIDIA GEFORCE GT 710



GPU cluster for AI applications.

Data processing center (CED)
of the Etnean Observatory.

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• PRODUCTS AVAILABLE

All products are collected in a WEB-GIS, named **Lav@Hazard**, based on Google Maps API: **http://ctmgweb.ct.ingv.it**

The web structure consists of 4 modules:

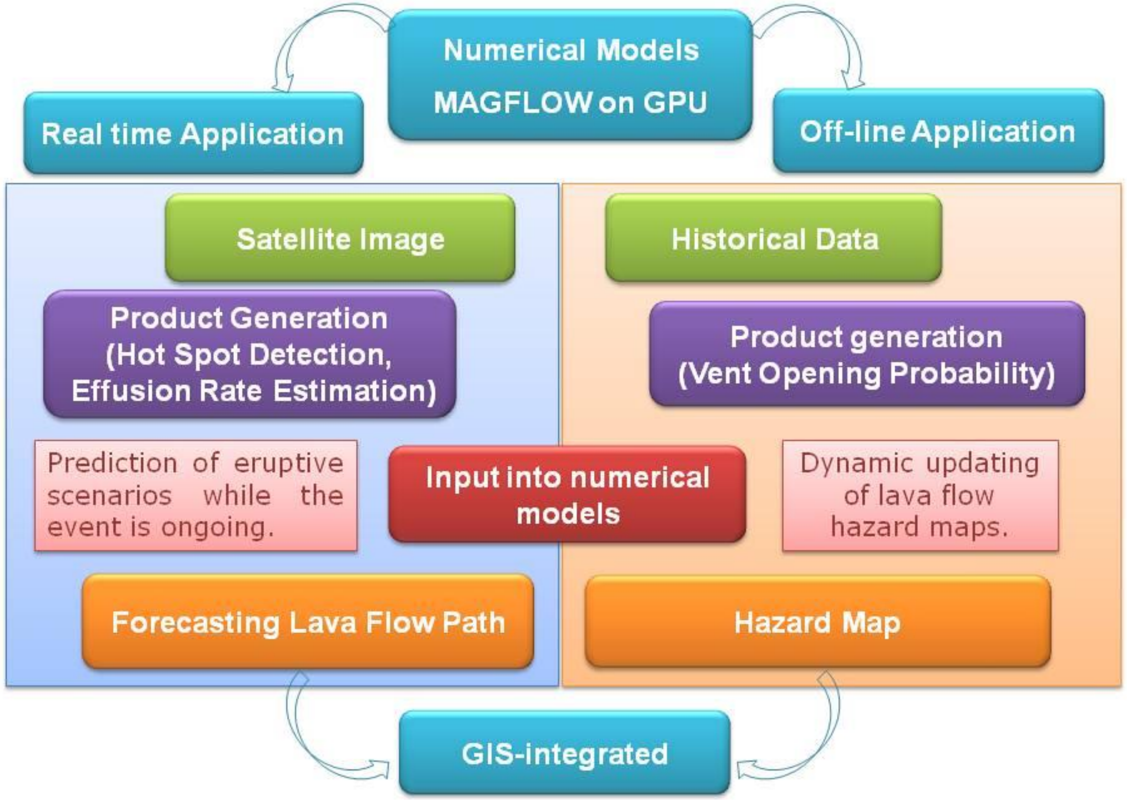
1. satellite applications by HOTSAT;

2. hazard map visualization;

3. database of lava flow simulations (about 30.000);

4. real-time scenario forecasting by MAGFLOW implemented in OpenCL.

5. report on the eruptive activity

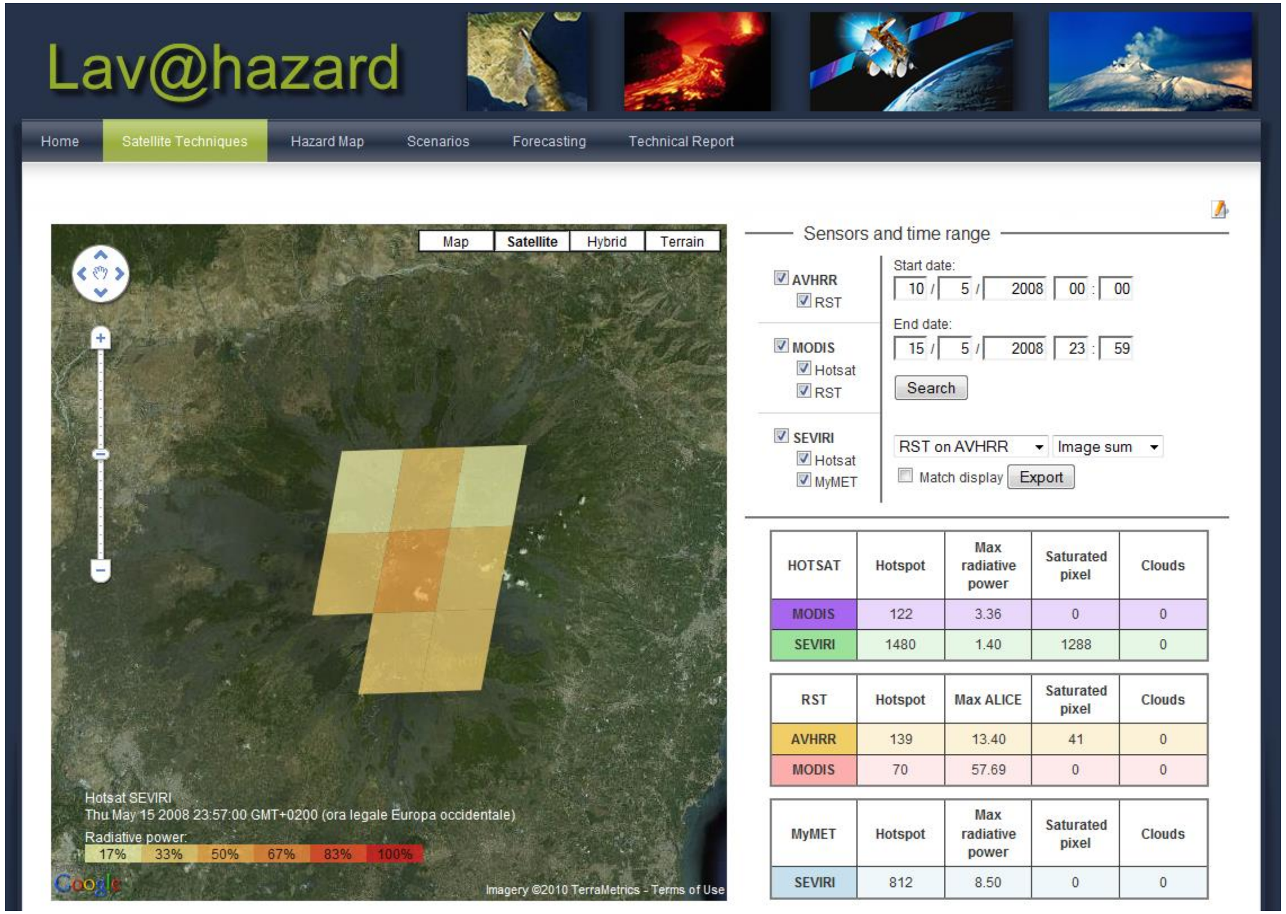


• PRODUCTS AVAILABLE

Lav@Hazard: Satellite Module

HOTSAT system in included for hotspot detection by using MODIS and SEVIRI images.

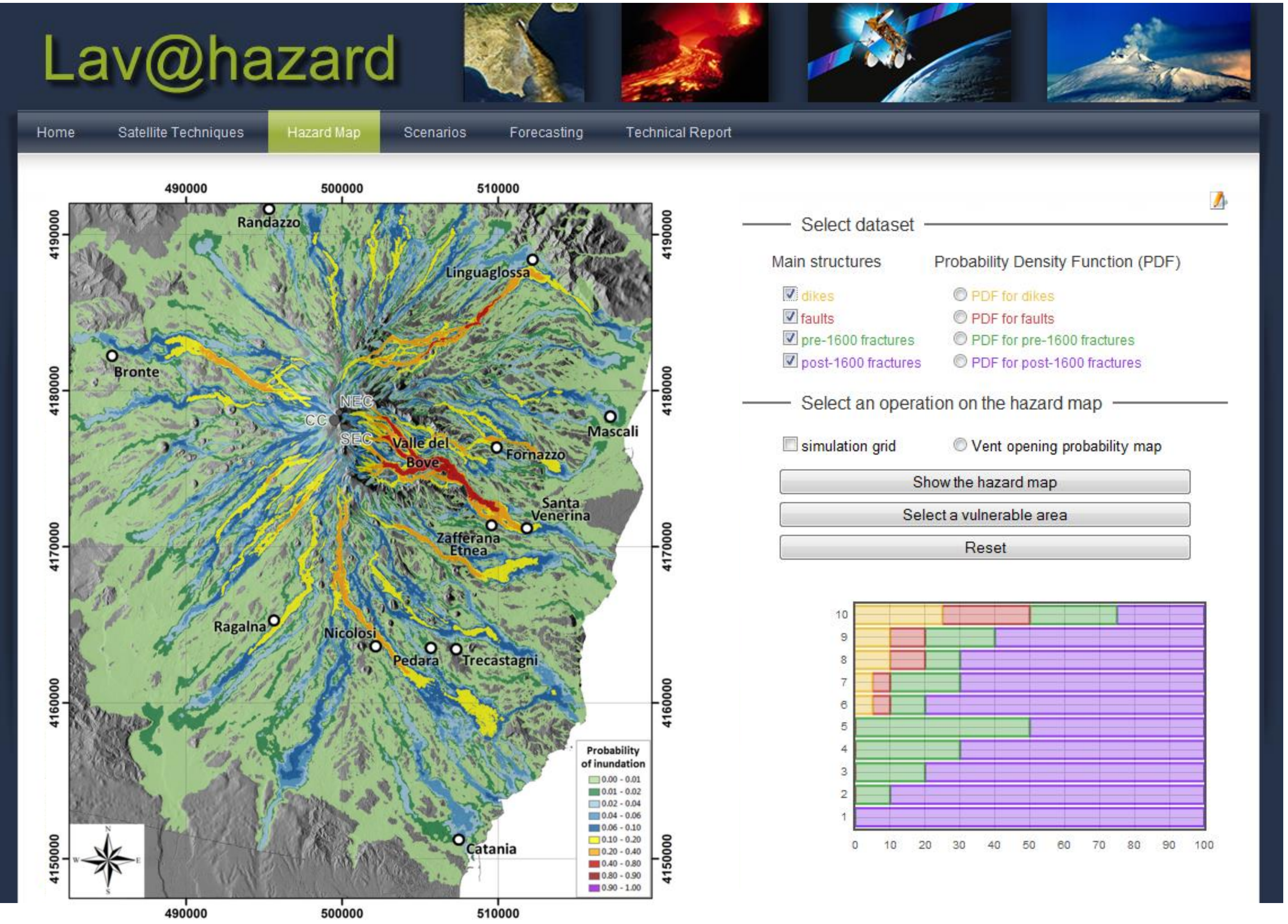
The radiative power is showed and the effusion rate is computed.



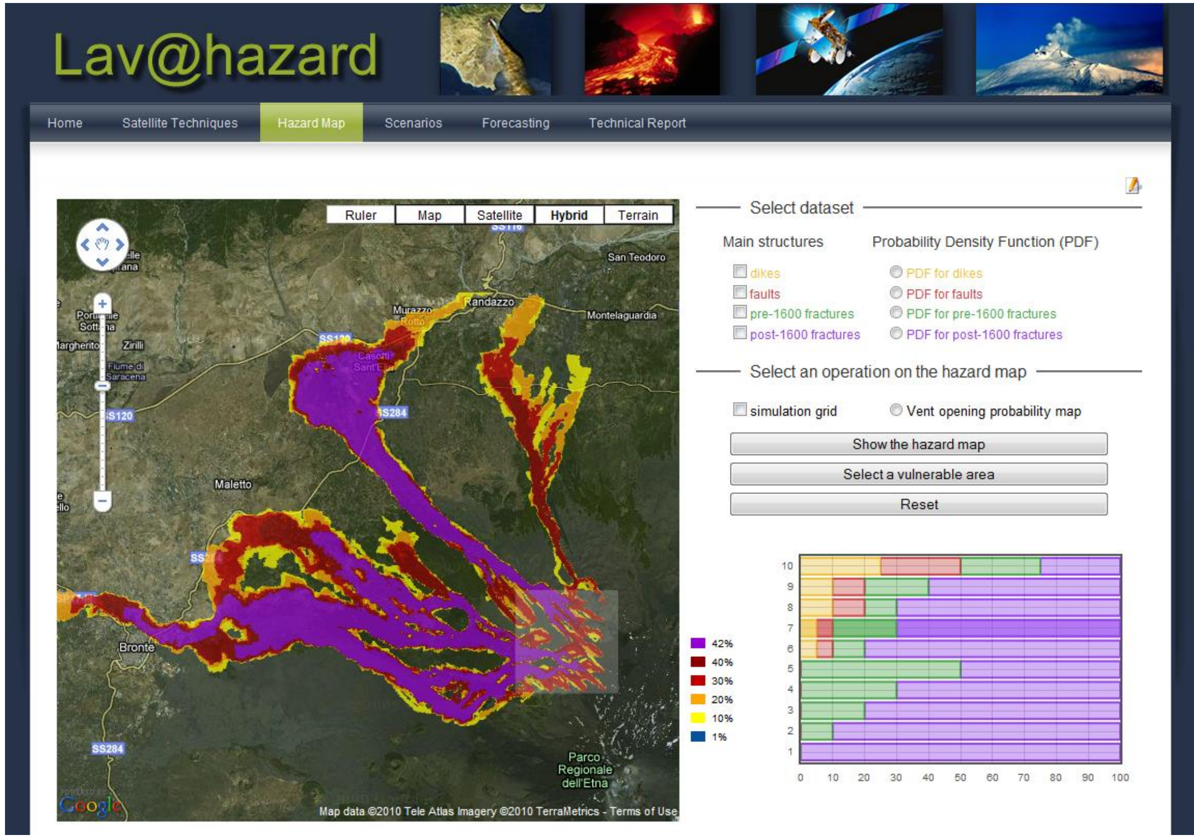
• PRODUCTS AVAILABLE

Lav@Hazard: Hazard Module

Lava flow hazard map for Etna flank eruptions.



Selection of a specific area and visualization of the hazard map obtained activating only the inner grid vents and assigning each of them the same activation and event probability.

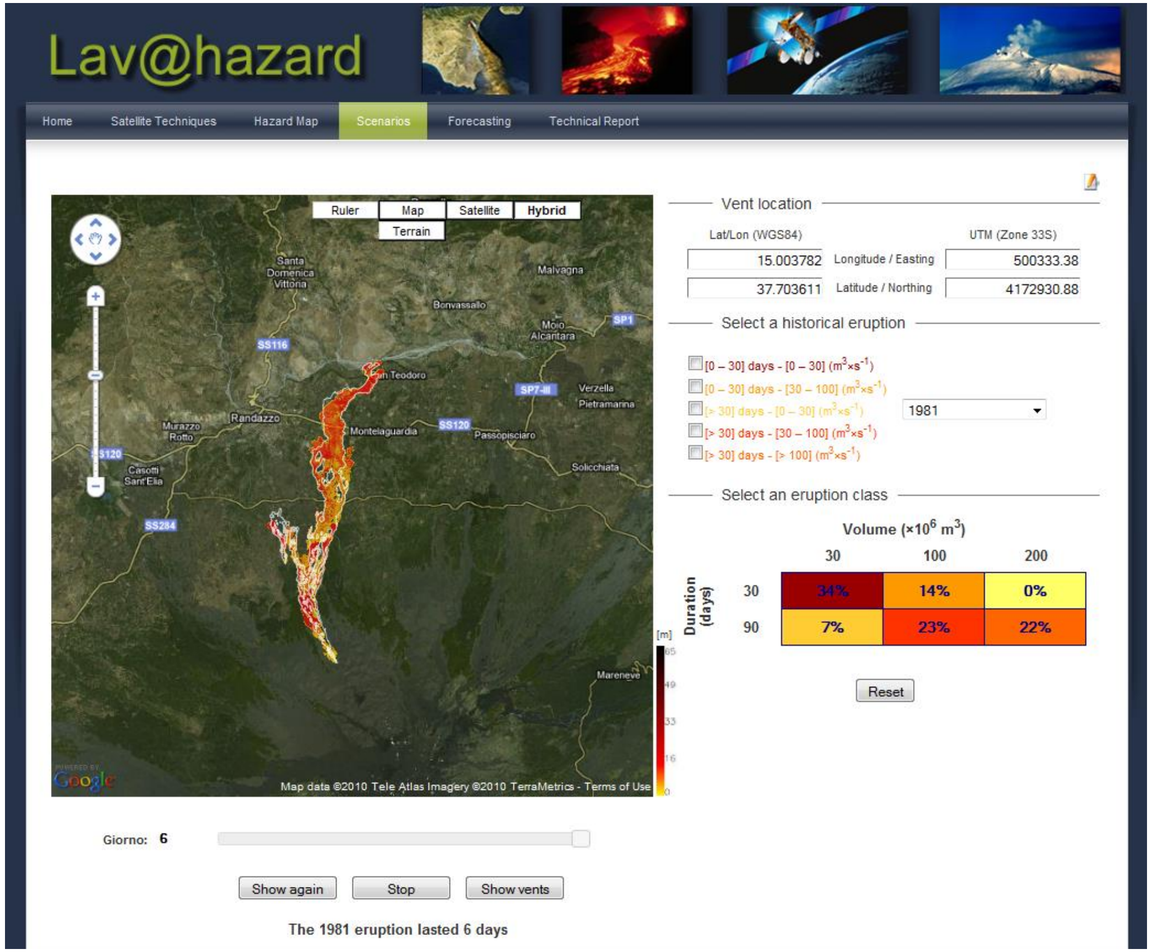


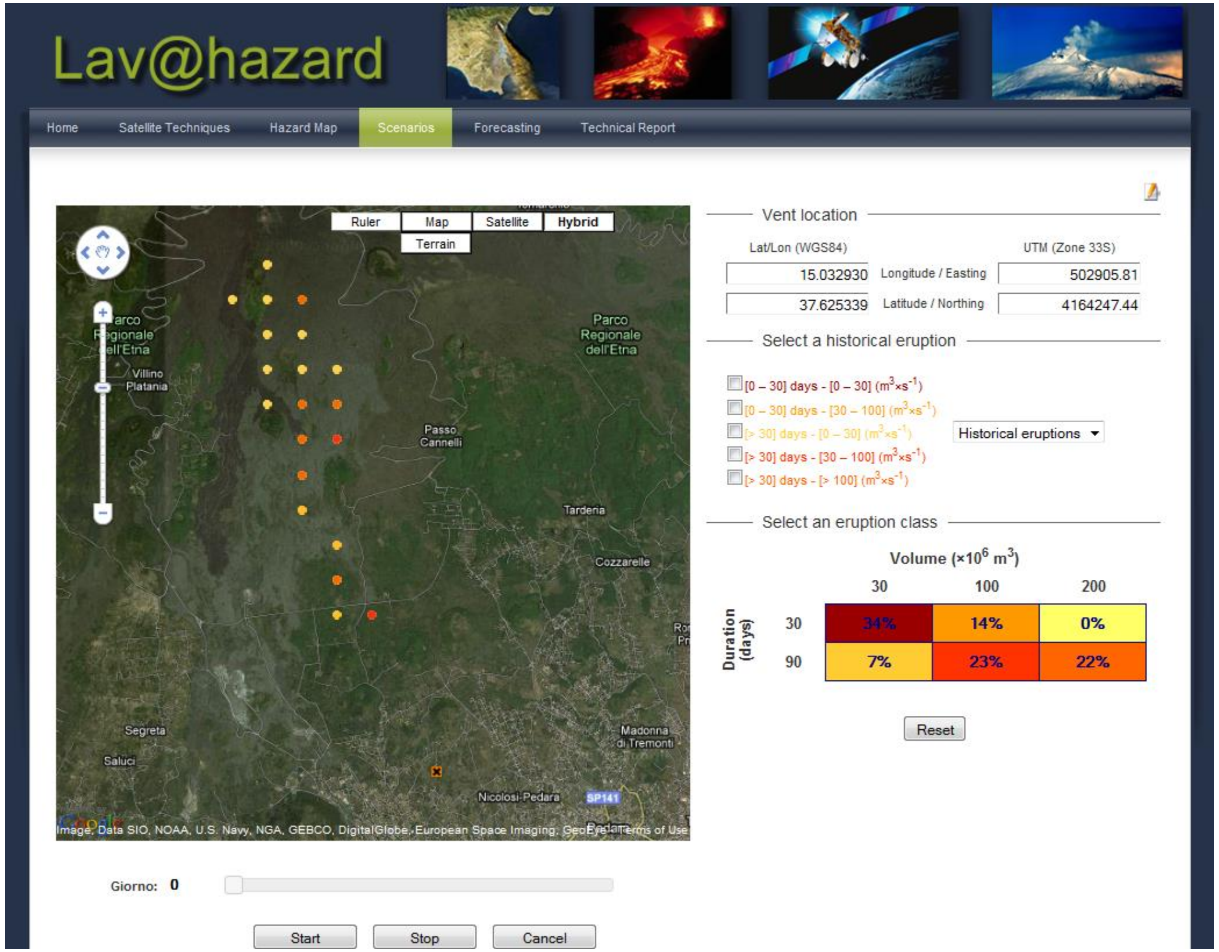
• PRODUCTS AVAILABLE

Lav@Hazard: Scenario Module

Historical eruptions simulated by MAGFLOW.

Visualization of all vents belonging to the simulation grid that produce eruptions that can invade a specific point, with the eruptive class associated and the altitude.

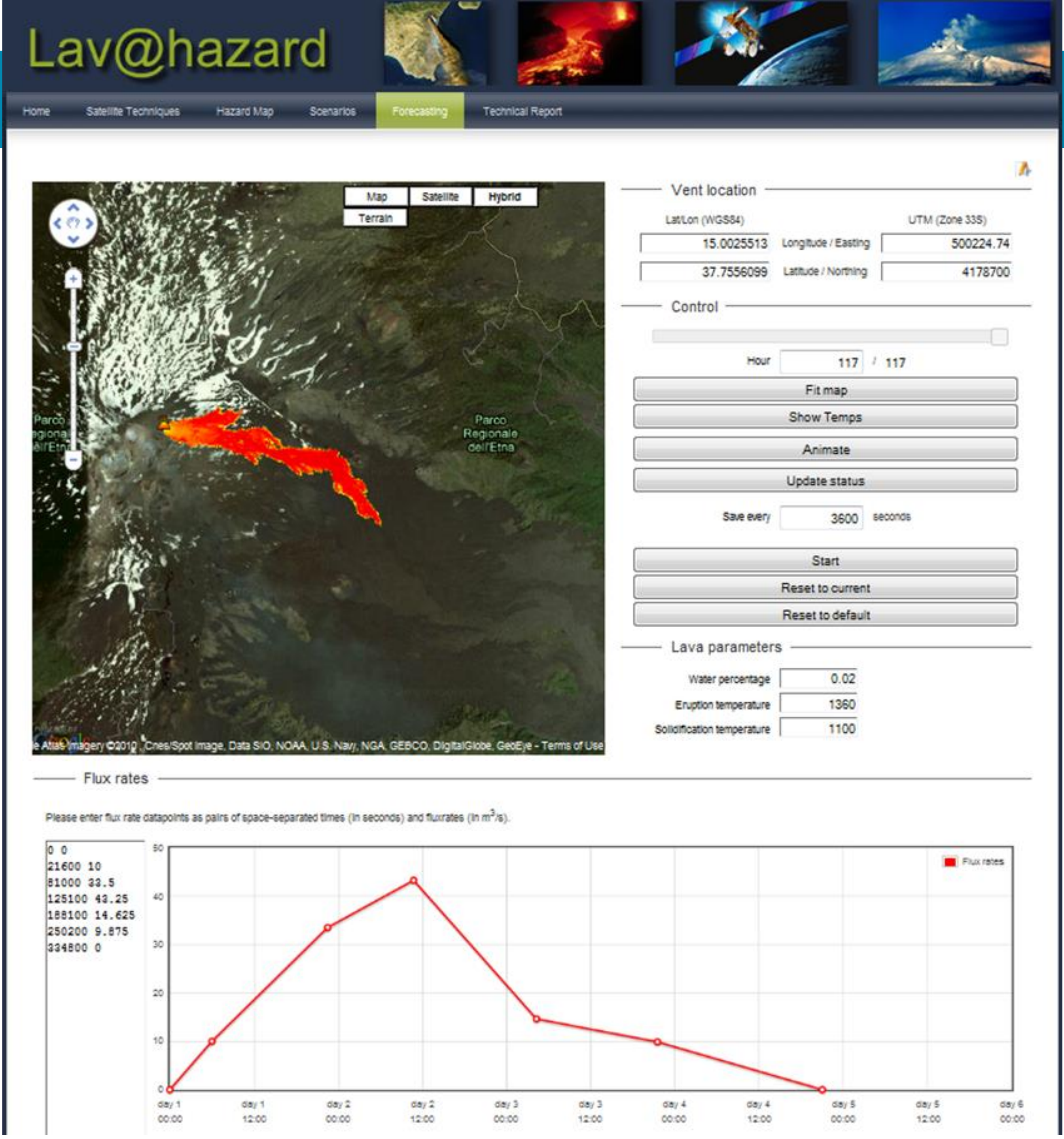




• PRODUCTS AVAILABLE

Lav@Hazard: Forecasting Module

This module allows control of the MAGFLOW simulator implemented in OpenCL. In this way the model is able to produce scenario forecast in real-time as required by web applications. The user can select a vent location, some physical and rheological parameters necessary for the model and the expected effusion rates.



• PRODUCTS AVAILABLE

Lav@Hazard: Report Module

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Rapporto sulla pericolosità a breve termine per attività effusiva all'Etna

Generato dalla piattaforma Lav@Hazard

Periodo di riferimento: dal 2019-07-26 02:00 CEST al 2019-07-28 02:00 CEST

Data emissione: 2019-07-27 19:32 CEST

Anomalie rilevate	Mappa di pericolosità preliminare

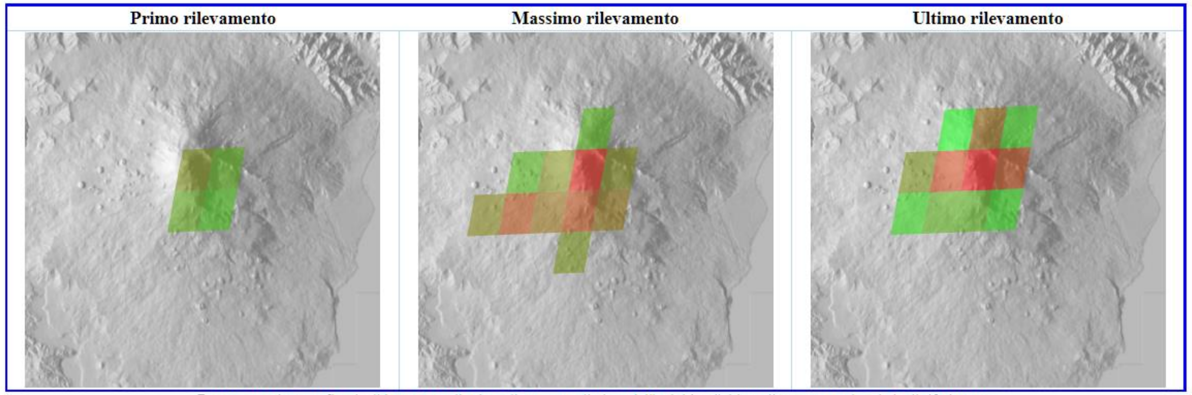
Anomalie rilevate

Nel periodo di riferimento (2019-07-26 02:00 CEST / 2019-07-28 02:00 CEST) sono stati rilevati 2 giorni di attività. Una sintesi delle anomalie termiche (hotspot) rilevate all'inizio, al picco ed alla fine dell'attività sono presentate nella seguente tabella:

	Data	Hotspot	Saturi	VRP (GW)
Inizio	2019-07-27T08:45:10Z	4	0	3.09
Massimo	2019-07-27T14:45:09Z	11	0	11.98
Fine	2019-07-27T16:45:10Z	11	0	9.89

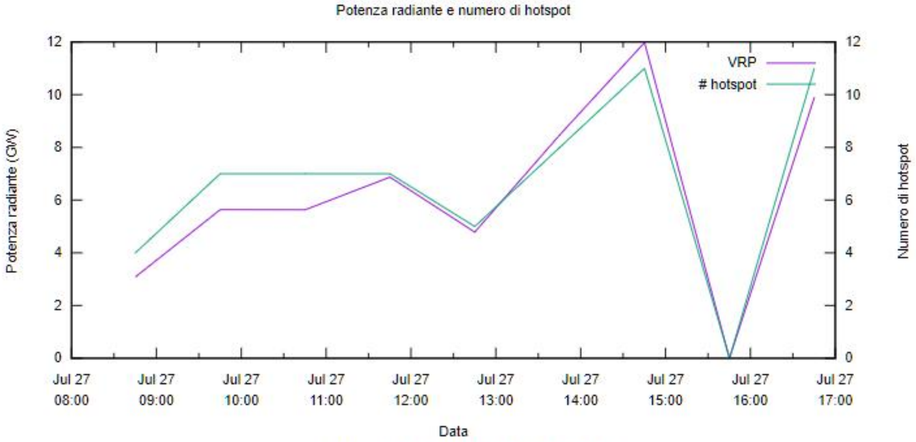
Numero di hotspot, numero di hotspot saturi e potenza radiante (VRP) stimata per il primo rilevamento, il picco dell'attività, e l'ultimo rilevamento nel periodo di riferimento.

La distribuzione spaziale delle anomalie termiche nel rilevamento iniziale, di picco e finale è rappresentata nella seguente figura:



Rappresentazione grafica degli hotspot per il primo rilevamento, il picco dell'attività, e l'ultimo rilevamento nel periodo di riferimento.

L'andamento della potenza radiante (VRP) stimata e del numero di anomalie identificate nel tempo è rappresentato nel seguente grafico:



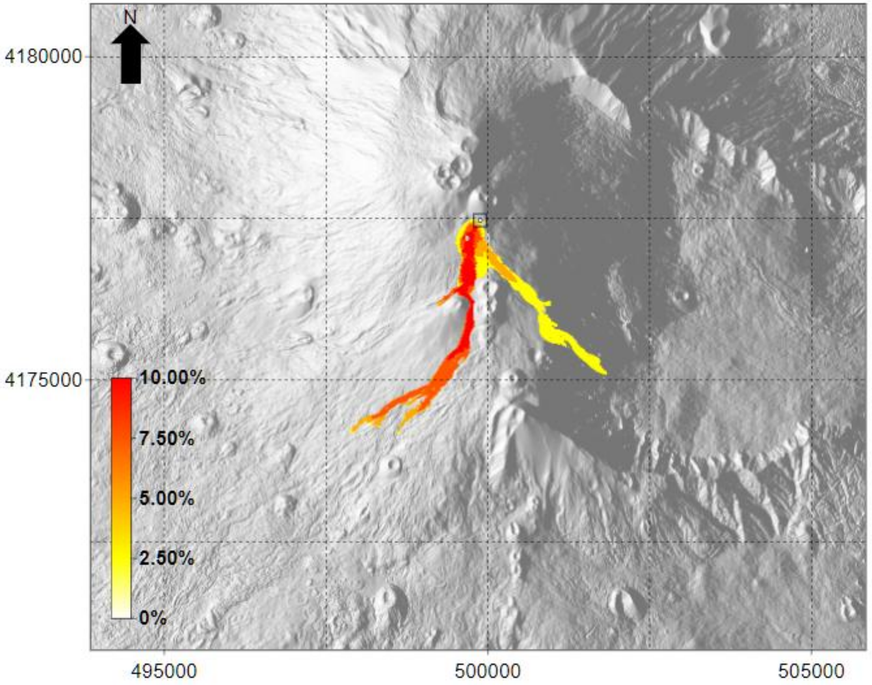
Potenza radiante e numero di hotspot rilevati nel periodo

Intengrando il TADR (Time-Averaged Discharge Rate) stimato dalla potenza radiante si ottiene una stima di volume totale di 303.4×10^3 m^3.

Mappa di pericolosità preliminare

La posizione della bocca (impostata dall'operatore) ha easting, norting 499885.00, 4177467.00 metri (sistema di riferimento UTM, zona 33S, emisfero nord, con datum WGS-84).

Una mappa di pericolosità a breve termine estratta dalla mappa sommitale a lungo termine in un intorno di raggio 100m (8 bocche, 10 classi eruttive per bocca) è rappresentata in figura.



Mappa di pericolosità a breve termine derivata dalla mappa sommitale a lungo termine, selezionando le bocche in un intorno di 100m della posizione della bocca (impostata dall'operatore) (UTM-WGS84 33S: 499885.00, 4177467.00)

• SATELLITE DATA-SOURCES

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	3-4 looks a day	Radiant Heat Flux
VIIRS	375 m	3-4 looks a day	Radiant Heat Flux
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
EO-ALI	10 - 30 m	On demand	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
Sentinel 1	10 – 40 m	12 days	Lava flow area

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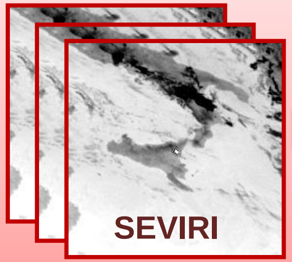
• LAVA FLOW HAZARD MONITORING FROM SPACE

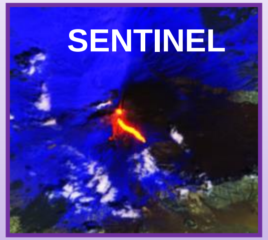
Lav@Hazard: hazard modeling driven by satellite-derived parameters

High Spatial Resolution Optical Images in Stereo-Tristereo

Low Spatial High Temporal Resolution Multispectral Images



Low Temporal High Spatial Resolution Multispectral Images



Lav@Hazard

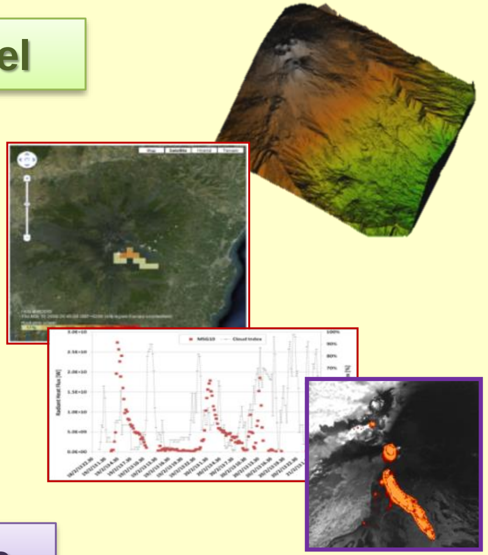
1. Digital Elevation Model

2. Hotspot Detection

3. Radiant Heat Flux

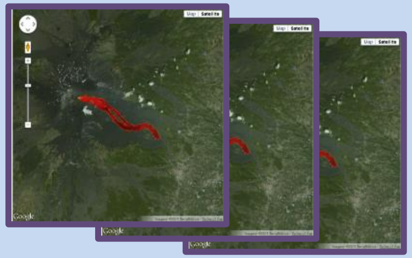
4. TADR Estimation

5. Active Lava Flow Area



FLOWSAT

6. Eruptive scenarios



MAGFLOW

Lav@Hazard shows how free access to a diversity of remote sensing data over volcanoes can benefit hazards modeling efforts.

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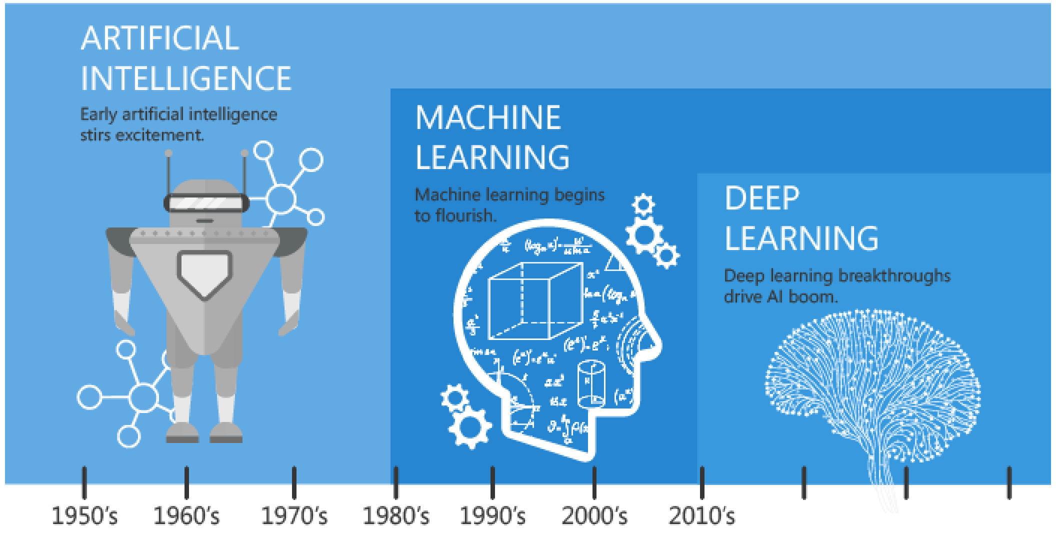
• MACHINE LEARNING



Grants for doctoral students

2020-2023
- PhD in Engineering, University of Catania
- PhD in Mathematics, University of Palermo

2021-2024
- PhD in Computer Science, University of Catania

Volcano Hazard Monitoring from Space using Machine Learning (ML) Methods

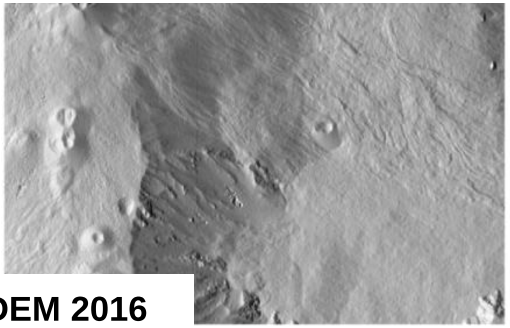
Monitoring of volcanic hazards presents extraordinarily challenging problems, from detecting and quantifying hazardous phenomena during eruptive events to forecasting their impact to assess risks to people and property. Helping address these problems, however, is an abundance of satellite data-sets with ever-improving temporal, spatial, and spectral resolutions that are mostly open and publicly available.

This exceptional combination of pressing challenges and abundant data is leading to the growing use of data-driven approaches, including machine learning models, to solve problems of volcanic hazards. Machine learning, a type of AI in which computers learn from data, is gaining importance in volcanology, not only for monitoring purposes (i.e., in real-time) but also for later hazards analysis (e.g. modelling tools).

• PRODUCTS AVAILABLE

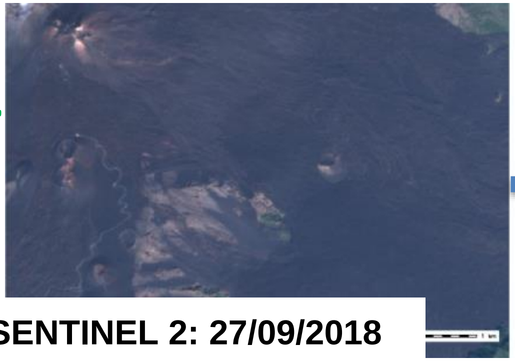
Mapping cooled new lava flow field using BNN (1/2)

Topography



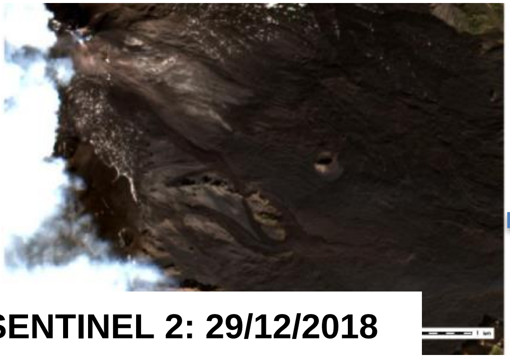
DEM 2016

Pre-eruptive



SENTINEL 2: 27/09/2018

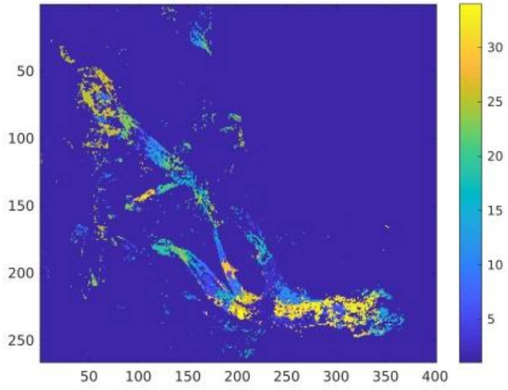
Post-eruptive



SENTINEL 2: 29/12/2018

Non-Supervised Classifier

34 classes identified for the cool lava field

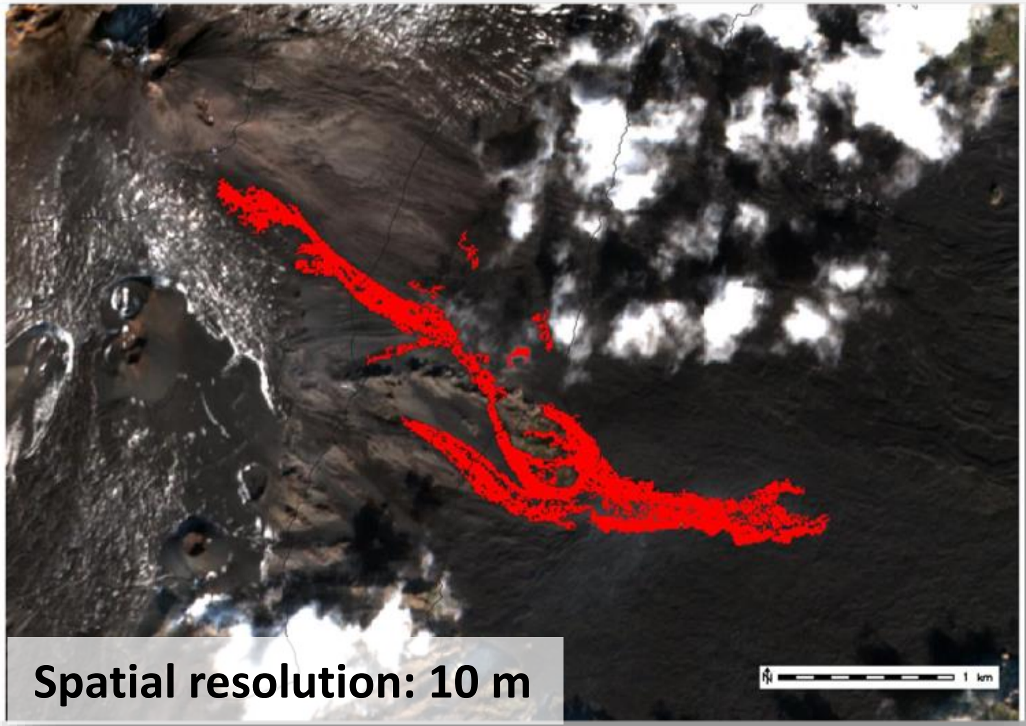


For each MSI image, Band 2 (492.4 nm), Band 3 (559.8 nm), Band 4 (664.6 nm), and Band 8 (832.8 nm) were considered.

TRAINING INPUT:

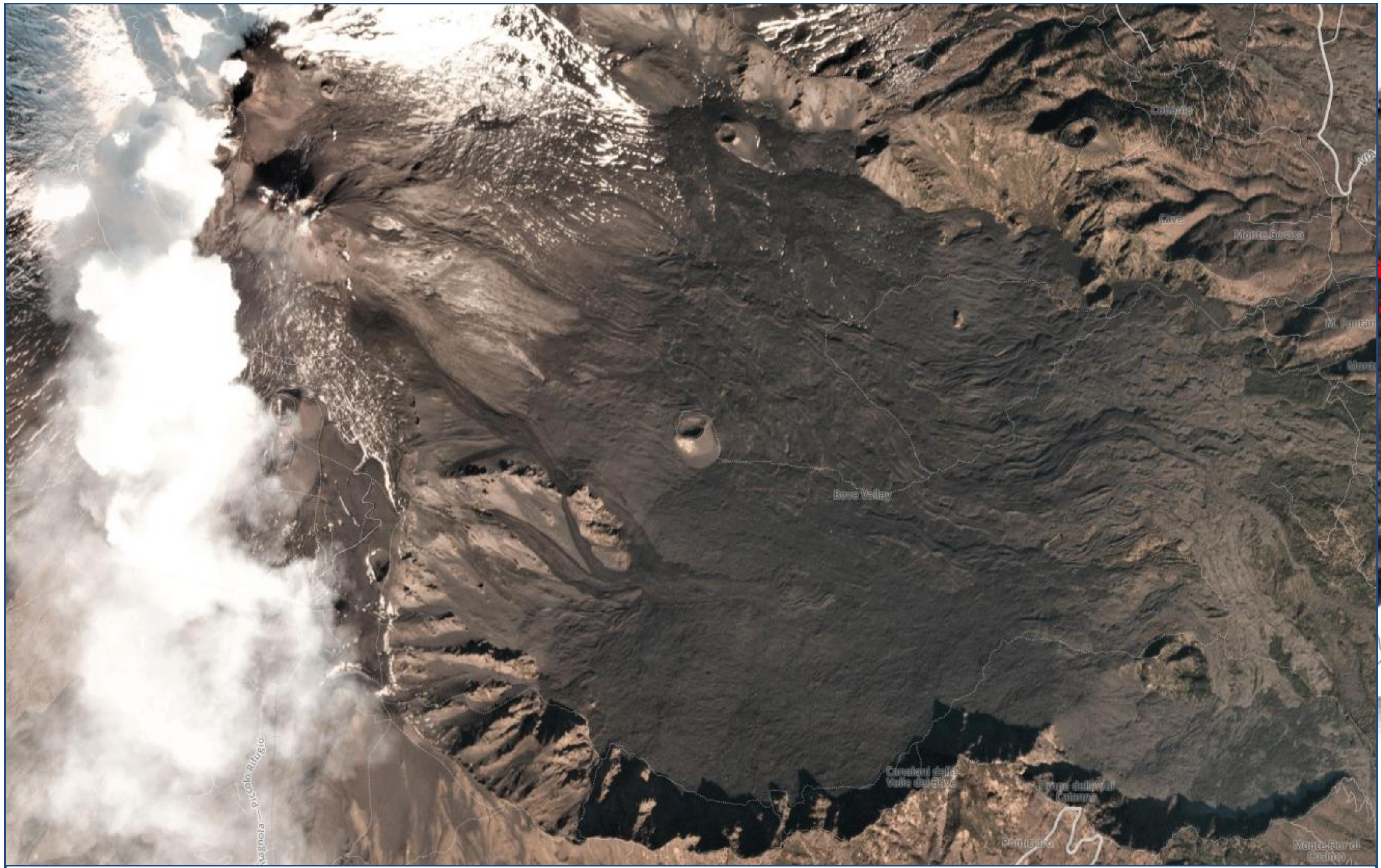
34 training pixels each one belonging to one of the 34 classes

Bayesian Neural Network (BNN)



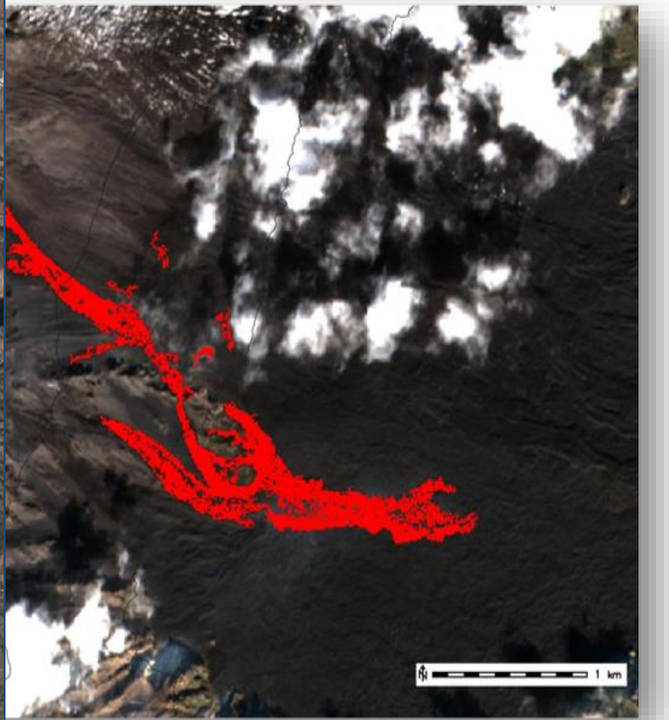
• PRODUCTS AVAILABLE

Mapping cooled new lava flow field using BNN (2/2)



PlanetScope: 09h19m 29DEC2018 [spatial resolution: 3 m]

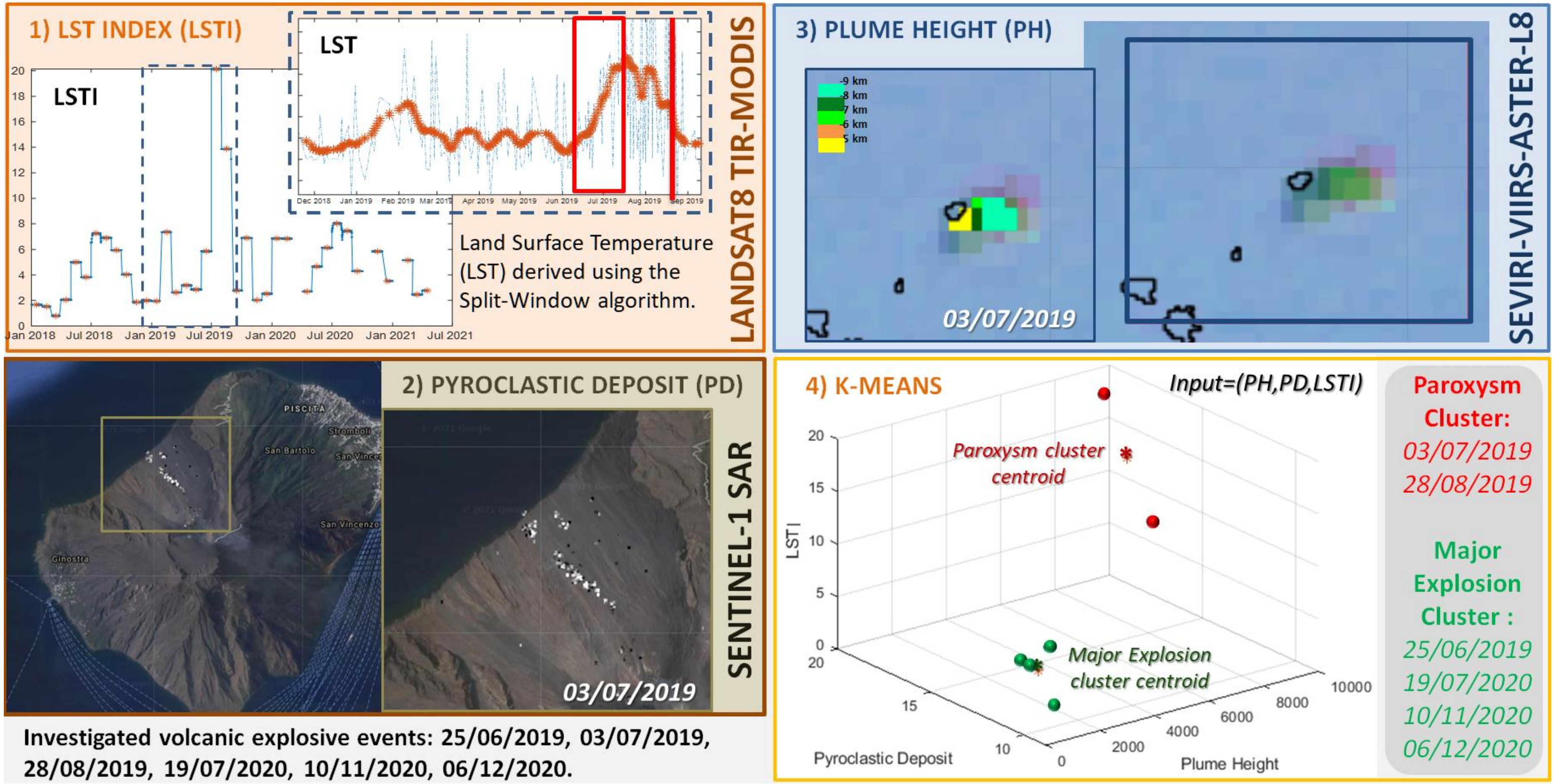
Area BNN ≈ 810,000 m²



Area PlanetScope ≈ 880,000 m²

• PRODUCTS AVAILABLE

Machine learning classifiers for detecting and classifying major explosions and paroxysms at Stromboli volcano using radar and optical satellite imagery



Investigated volcanic explosive events: 25/06/2019, 03/07/2019, 28/08/2019, 19/07/2020, 10/11/2020, 06/12/2020.

• CURRENT DISTRIBUTION OF PRODUCTS

DIPARTIMENTO DI PROTEZIONE CIVILE

@ **Sala Operativa dell’Osservatorio Etneo**

@ **Bollettino settimanale stato attività Etna**

@ **Bollettino settimanale stato attività Stromboli**

@ **Comunicati straordinari sullo stato di attività dei vulcani siciliani**

• PROGRAMS/PROJECTS OF REFERENCE

 # ATHOS research programme (2017-2022)

Total Budget: € 200.000

 # Convenzione INGV-DPC Allegato A

Budget: € 7200 in 2020

 # Progetto Strategico Dipartimentale FIRST (2020-2023)

Total Budget: € 20.000 => PhD in Computer Science

• TEAM AND AFFILIATIONS

Ciro Del Negro
Research Director

Sonia Calvari
Research Director

Gaetana Ganci
Researcher

Annalisa Cappello
Researcher

Giuseppe Bilotta
Researcher

Claudia Corradino
Research Fellow

Eleonora Amato
PhD Student

Federica Torrisi
PhD Student

Alexis Hérault
Associate Researcher

Laboratory of Technology for Volcanology
Etna Volcano Observatory – INGV-CT

TechnoLab

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- ***Sonia Calvari***, Research Director, INGV-OE
- ***Gaetana Ganci***, Researcher, INGV-OE
- ***Annalisa Cappello***, Researcher, INGV-OE
- ***Giuseppe Bilotta***, Researcher, INGV-OE
- ***Claudia Corradino***, Research Fellow, INGV-OE
- ***Eleonora Amato***, PhD Student in Mathematics, University of Palermo
- ***Federica Torrisi***, PhD Student in Engineering, University of Catania
- ***Alexis Herault***, Associate Researcher, CNAM-Parigi, France

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• WORK IN PROGRESS