The Mount Etna case study 2021-2022: Integration of multiplatform remote sensing techniques - drones, satellites, and fixed surveillance cameras - to timely mapping and quantify volcanic lava flows.

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REMOTELY PILOTED AIRCRAFT
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Etna → persistent activity from its four summit craters.

Advance the understanding of the complex dynamics of the Earth System, encompassing both its solid and fluid components, and critically, to contribute to the mitigation of natural risks associated with these dynamics.

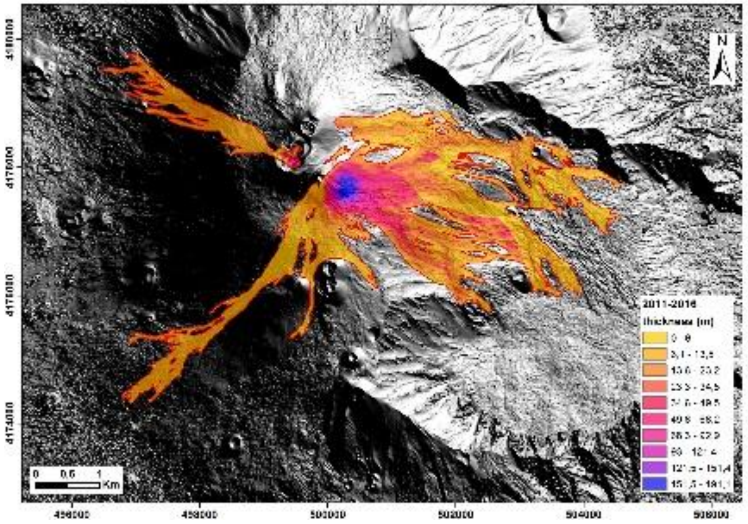
three main pillars:
Research and Development
Surveillance and Monitoring
Public Engagement and Education

Since 2011 Etna eruptive activity mostly occurred at the South East Crater (SEC)

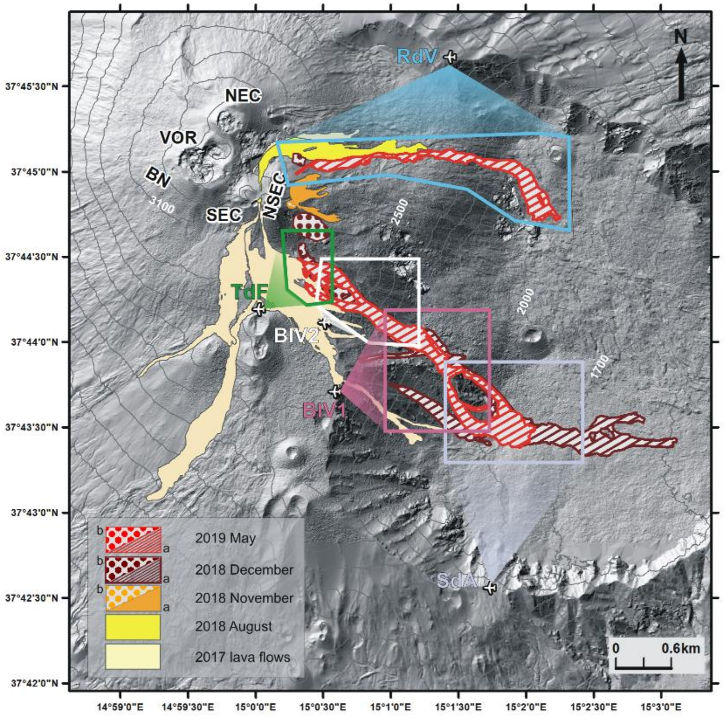
2011 - 2016:

45 powerful lava fountain episodes → formation of a compound lava field

Figure from Proietti et al. 2020



2017-2019



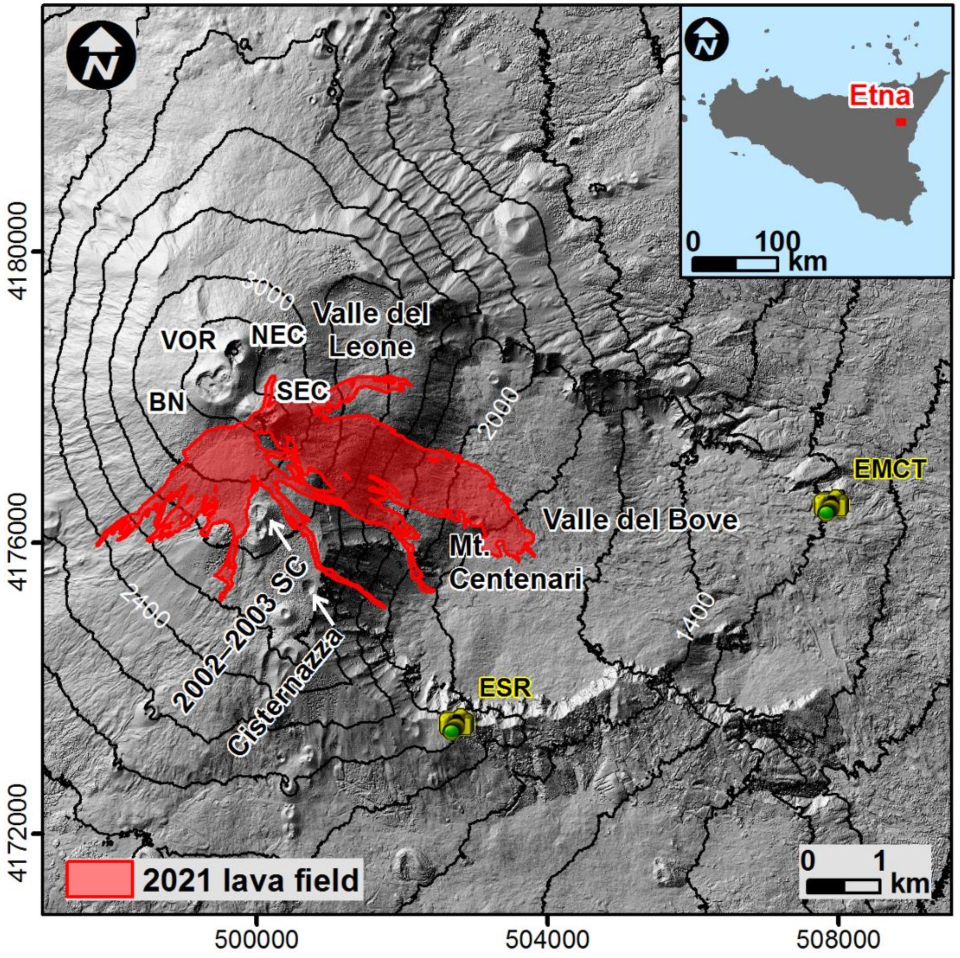
discontinuous vigorous Strombolian activity and effusive activity both from lateral fissures on and on the high SE flank

Figure from De Beni et al. 2020

2021

Extraordinary eruptive activity: 57 SEC episodes on 8 months → two cycles (16/02 – 31/03 and 19/05 – 23/10)

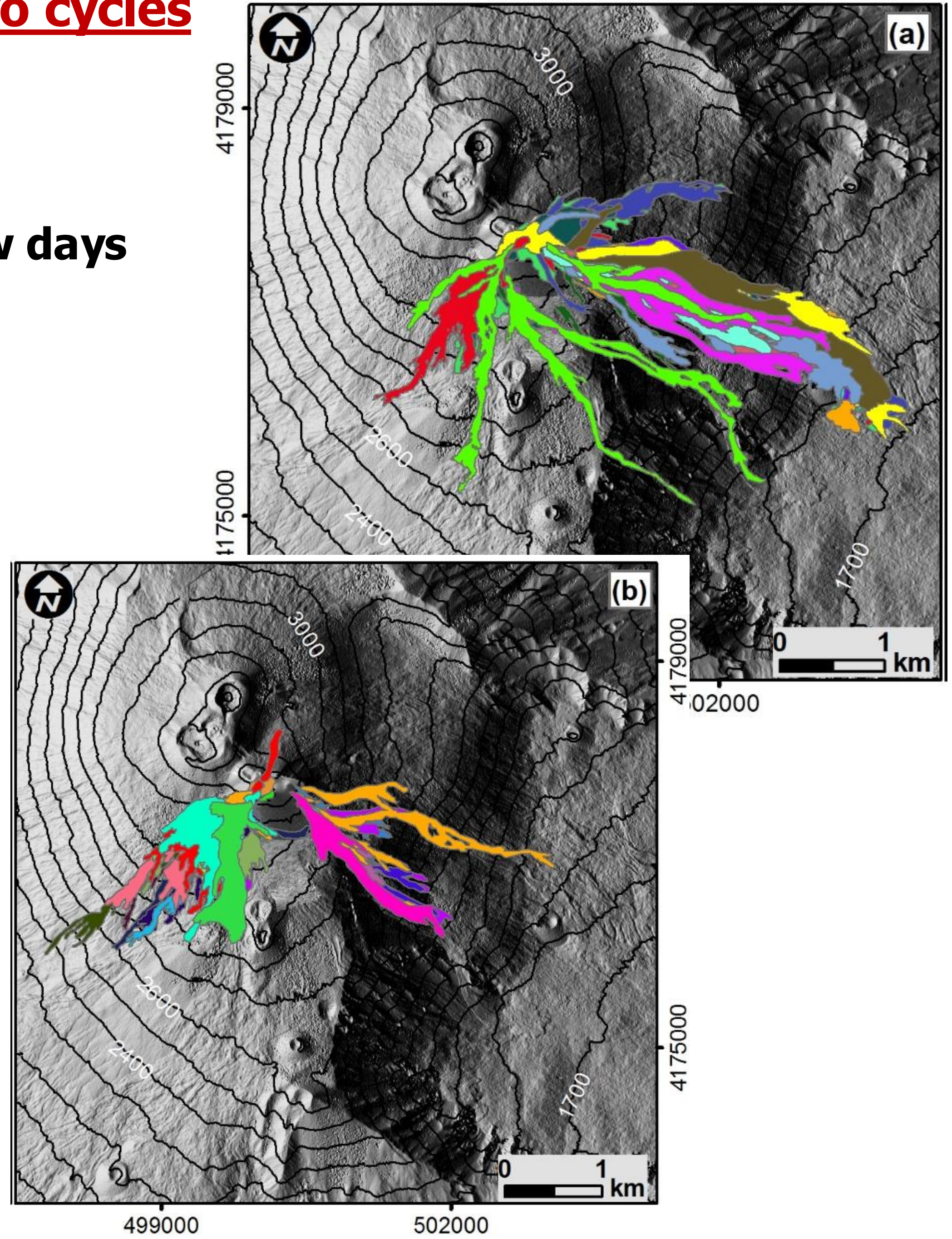
Strombolian activity, lava fountains and lava flows → formation of a compound lava field



The 2021 SEC eruptive activity can be divided into two cycles

I cycle (16/02 – 01/04): 17 episodes
Lava fountains lasting from ~1 h to ~7 h
Lava flows, towards E and SW, lasting from few hours to few days
Time interval between subsequent episodes of 3 h – 8 d

II cycle: 19/05 – 23/10 40 episodes
Lava fountains lasting from ~1 h to ~4 h
Lava flows, towards E and SW, lasting few hours
Time interval between subsequent episodes of 4 h – 32 d



What challenges have we faced for timely mapping the 2021 flows?

- **High frequency of the eruptive episodes**
- **Lava flows on two flanks at the same time**
- **Involved area visited by thousands of tourists**

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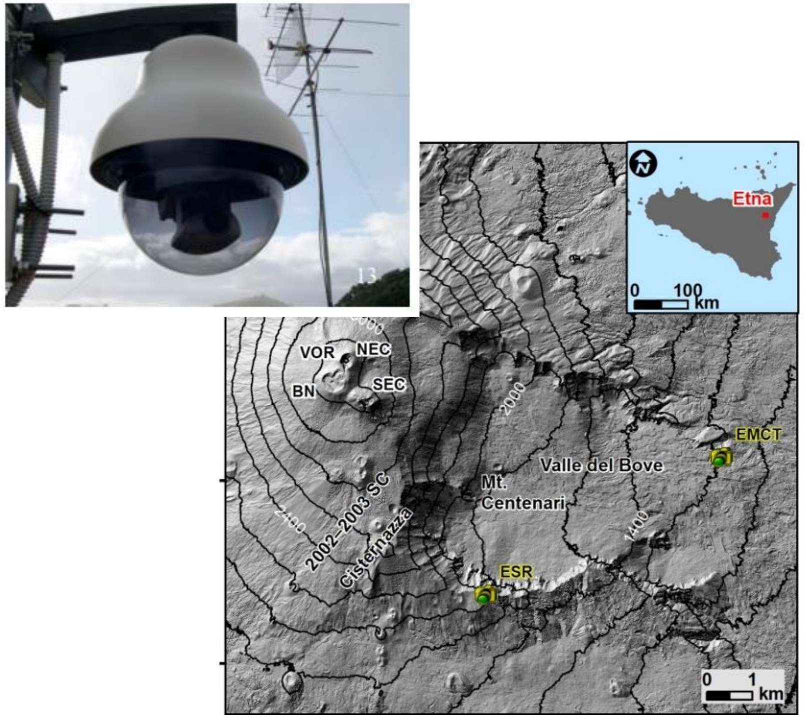
These tasks were faced by **integrating** data from different remote sensing platforms

Satellite

https://www.esa.int/Enabling_Support/
Operations/Sentinel-2_operations

Unoccupied Aerial System (UAS)

INGV-OE permanent network of cameras



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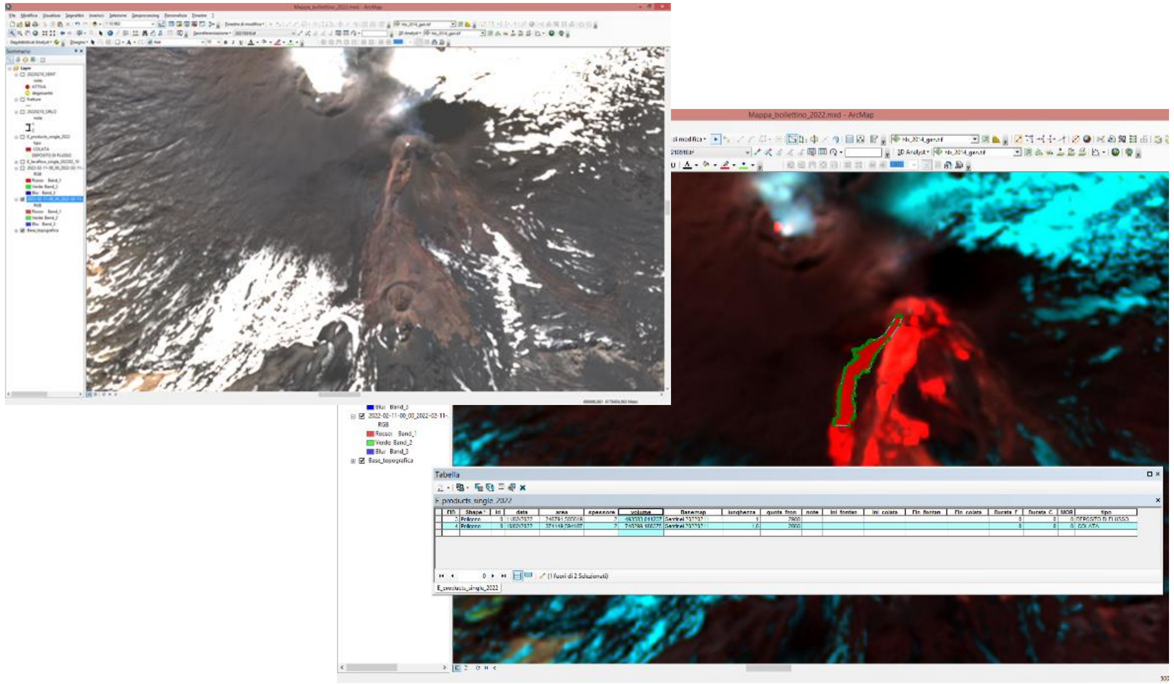
Satellite data: Sentinel-2, Aster, Ecostress, Skysat, Landsat-8

- Provide visible and near-infrared (SWIR) images
- Spatial resolution 1- 90 m

Downloaded **Orthorectified images**



https://www.esa.int/Enabling_Support/
Operations/Sentinel-2_operations

Disadvantages

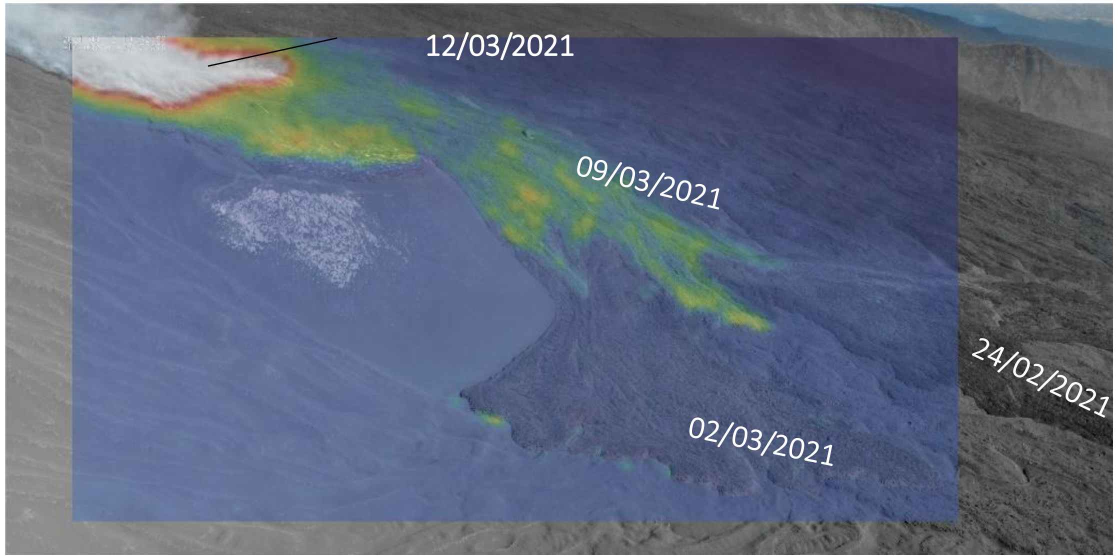
- Pre-scheduled acquisition times
  → visibility may be obscured by volcanic activity (plume) or bad weather
  → the revisiting time may be longer than the interval between consecutive events
- Lower spatial resolution → lower mapping accuracy

PE number	Analysed datasets (date)	LFl directions	Max L (km)	Min front el (m)
1	Skysat and Aster (17-02)	E, NE	4.0	1735
2	Skysat (18-02)	SW, E, NE	4.1	1740
3	Skysat (20-02)	SW, E	3.8	1740
4	Sentinel 2 (21-02)	E, SW	3.4	1870
5	Sentinel 2 (23-02)	SW, E, NE	3.0	1950
6	Sentinel 2 and Planescope (26-02)	SW, E	4.3	1700
7	Sentinel 2 (28-02)	SW, E	2.5	2050
8	Sentinel 2 (10-03), Planescope (06-03)	E	3.5	1760
9	Sentinel 2 (10-03), Planescope (06-03)	SW, E, NE	3.5	1780
10	EMCT (07-03)	E	3.3	1790
11	Planescope (11-03), UAS images (12-03)	E	3.3	1770
12	Sentinel 2 (13-03), Planescope (16-03), UAS images (12-03)	E,NE	3.2	1790
13	Planescope (16-03-2021), EMCT (14-03)	E, SE	2.7	1950
14	EMCT (17-03)	E	2.8	1930
15	Planetscope (24-03), EMCT (19-03)	E	2.4	2020
16	Sentinel 2 (25-03), EMCT (23-03), UAS images (27-03)	E, SE	2.5	1920
17	Sentinel 2 (04-04), Planetscope (01-04), ESR (02-04)	E,SE, SW	3.5	1820

Unoccupied Aerial System (UAS) data

- Provide visible and thermal images
- Sub-meter spatial resolution
- Flexibility of surveys

Orthomosaics and Digital Surface Model (DSM) extracted Through Structure from Motion (SfM) software



Disavantages

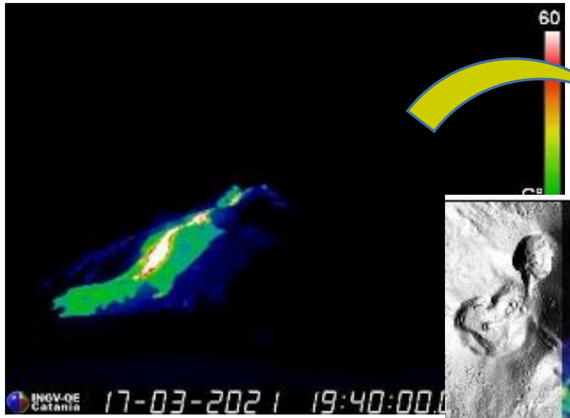
- Low flight altitude
- UAS are not allowed to fly BVLOS (Beyond Visual Line of Sight)
- UAS are disturbed by weather conditions

Survey date	UAS	Survey target	Goal	Covered area (km^2)	Number of images	DSM resolution (cm/px)	Orthomosaic resolution (cm/px)
03 March 2021	DJI Mavic Enterprise	SEC	Photogrammetry and Monitoring	1.07	60	55.0	14.0
12 March 2021	DJI Mavic Enterprise	VdB	Monitoring	-	174	-	-
27 March 2021	DJI Mavic 2 pro	VdB	Photogrammetry and Monitoring	15.8	277	48.9	12.2
29 March 2021	DJI Mavic Enterprise	SEC	Monitoring	-	544	-	-
16 Sept. 2021	DJI Phantom 4 pro	SEC	Photogrammetry and Monitoring	1.3	356	44.0	11.0
30 Sept. 2021	DJI Mavic Enterprise	SEC	Monitoring	-	70	-	-
04 Oct. 2021	DJI Mavic Enterprise	SEC	Monitoring	-	544	-	-
20 Oct. 2021	DJI Mavic Enterprise	SEC	Monitoring	-	584	-	-

INGV-OE permanent network of cameras

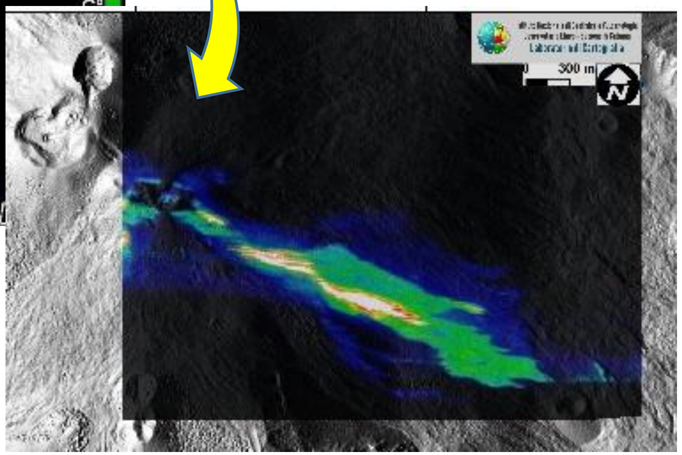
- Provide visible and thermal images in real time, high acquisition rate (2 frame/s) → enable following the lava flow temporal evolution

- Georeferenced thermal images are re-projected into the topography, through an algorithm developed in the framework of the WP2 - Task 11, DPC-B2 2019-21 (Ganci et al. 2013)
- 10 m spatial resolution



EMCT thermal image

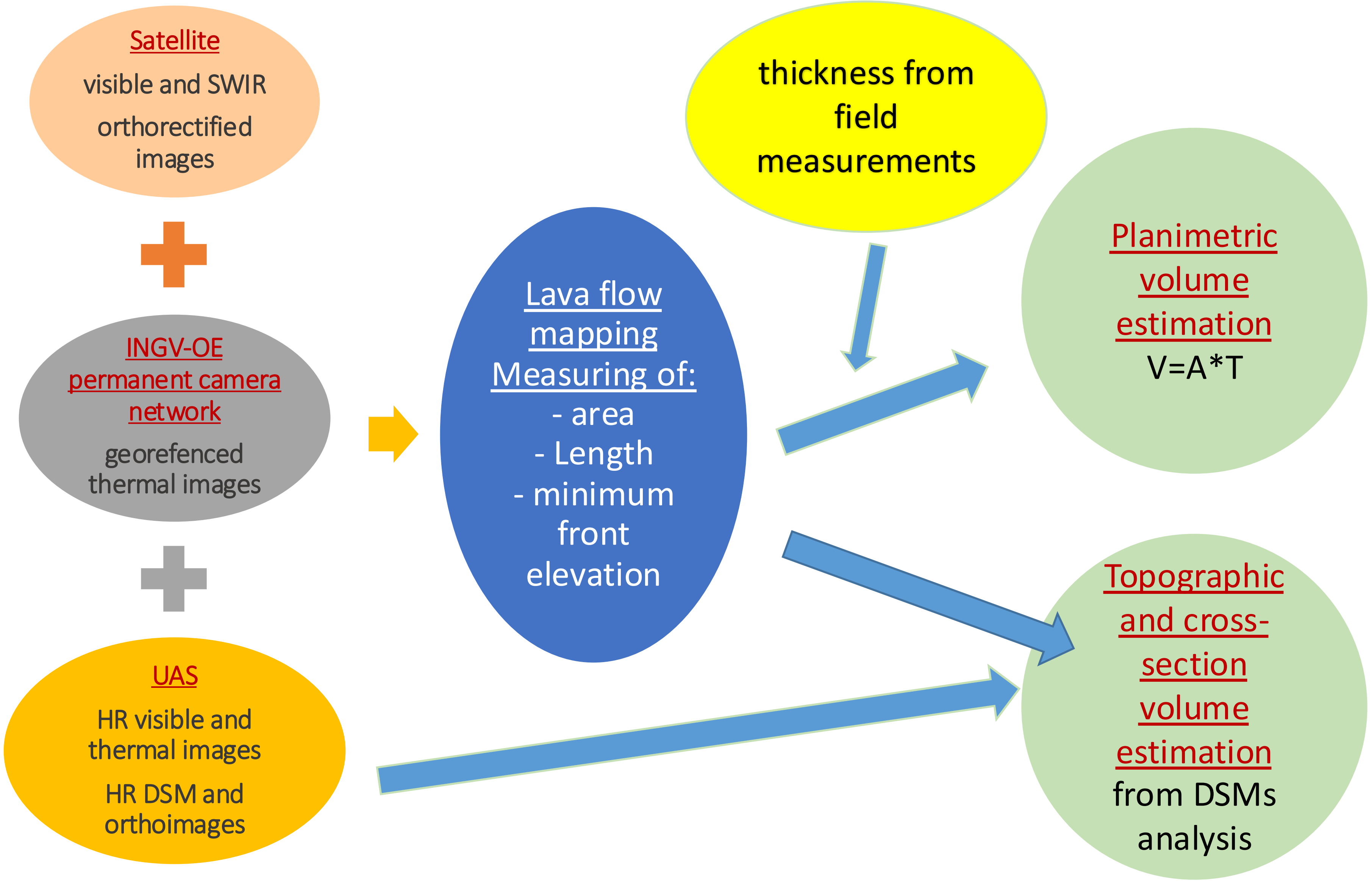
Orthorectified image



Disavantages

- Fixed positions -> possible partial or missing coverage of the area interested by a lava flow
- Possible image distortions when using not up-to-date DSM → morphological changes can result in shifts in the image georeferencing
- visibility may be hindered by volcanic activity (plume) or bad weather

The multi-sensor remote sensing data were jointly analysed trough a GIS software enabling us to:



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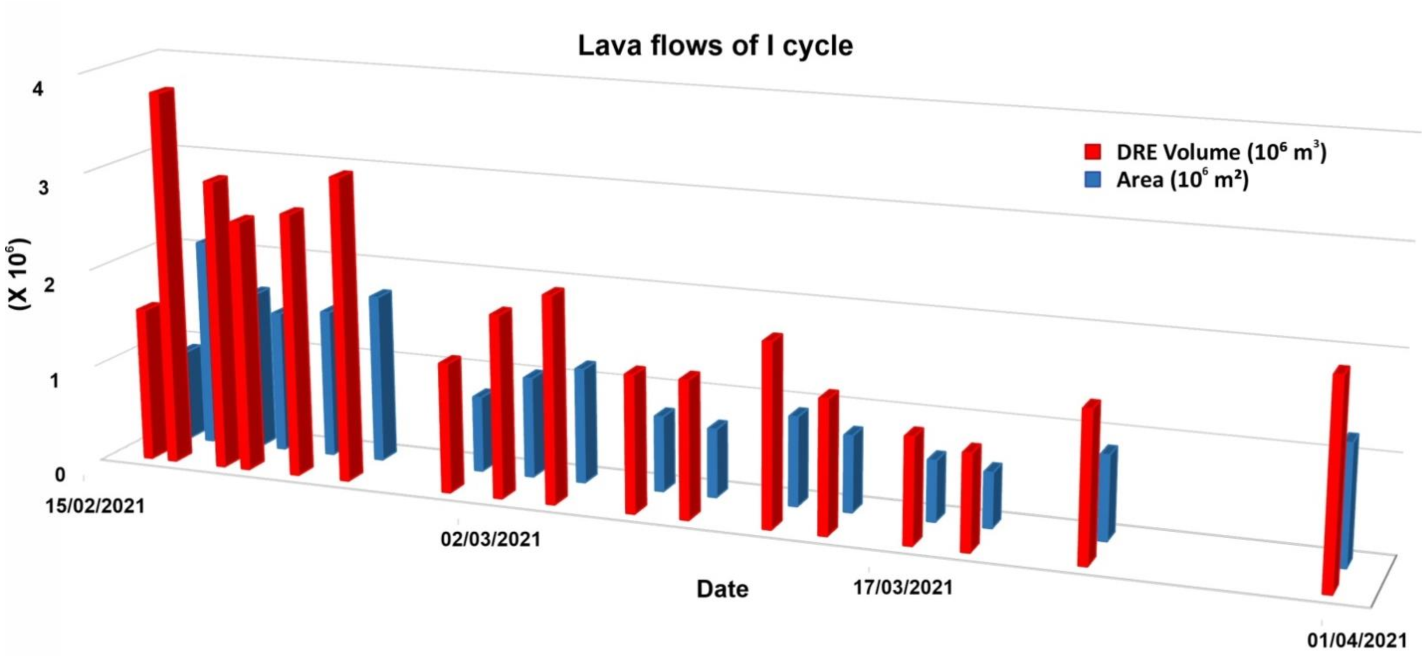
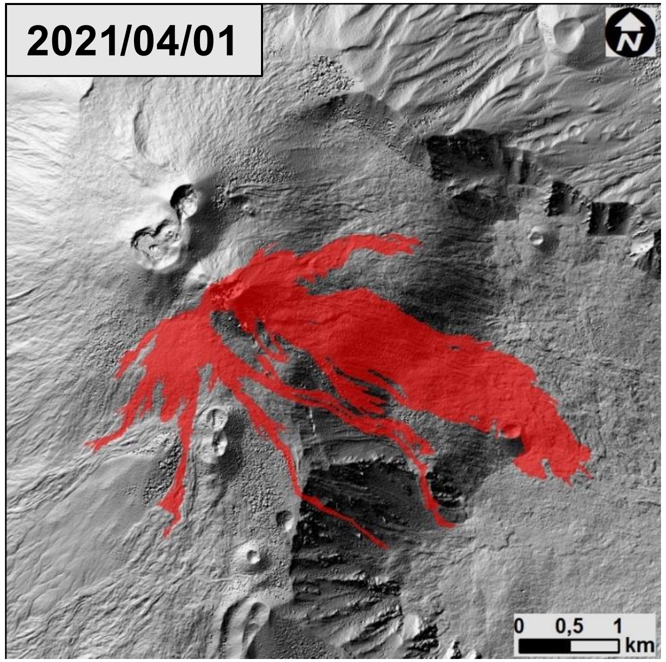
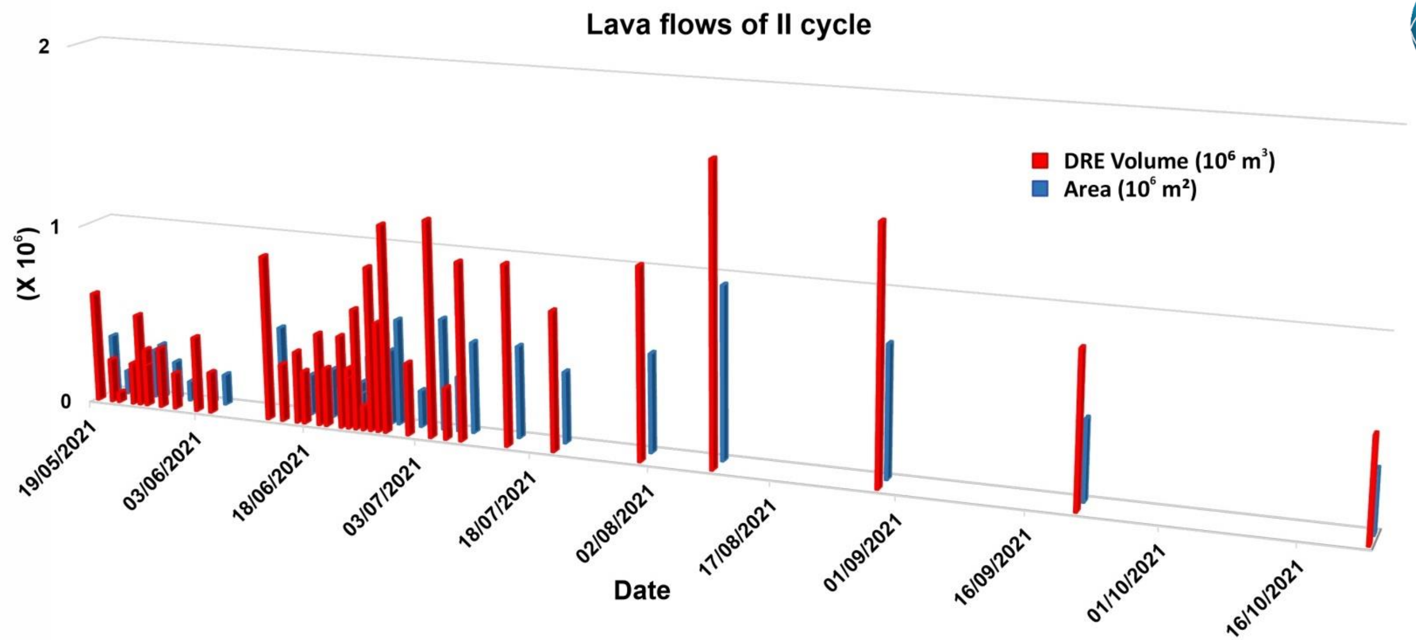




A_{cum}= 4.7 x 10^6 m^2
V_{total}= 42 x 10^6 m^3
Av thick= 8.9 m



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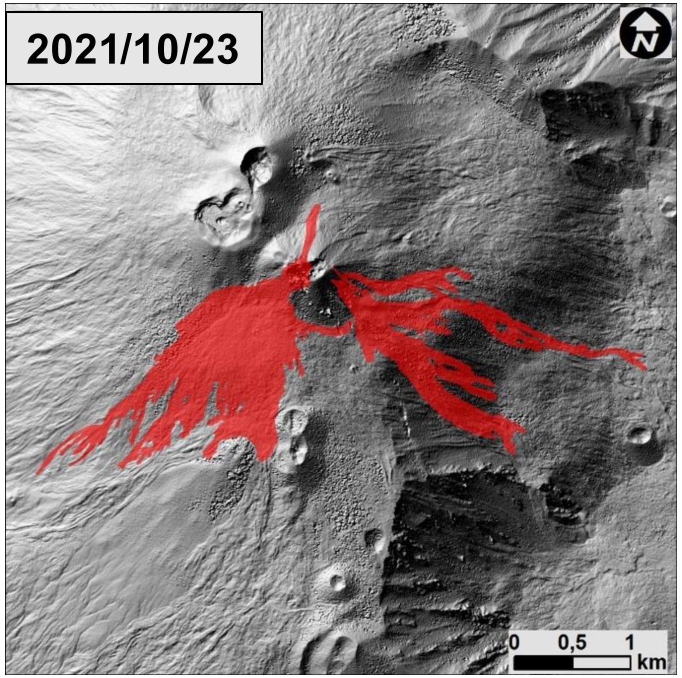
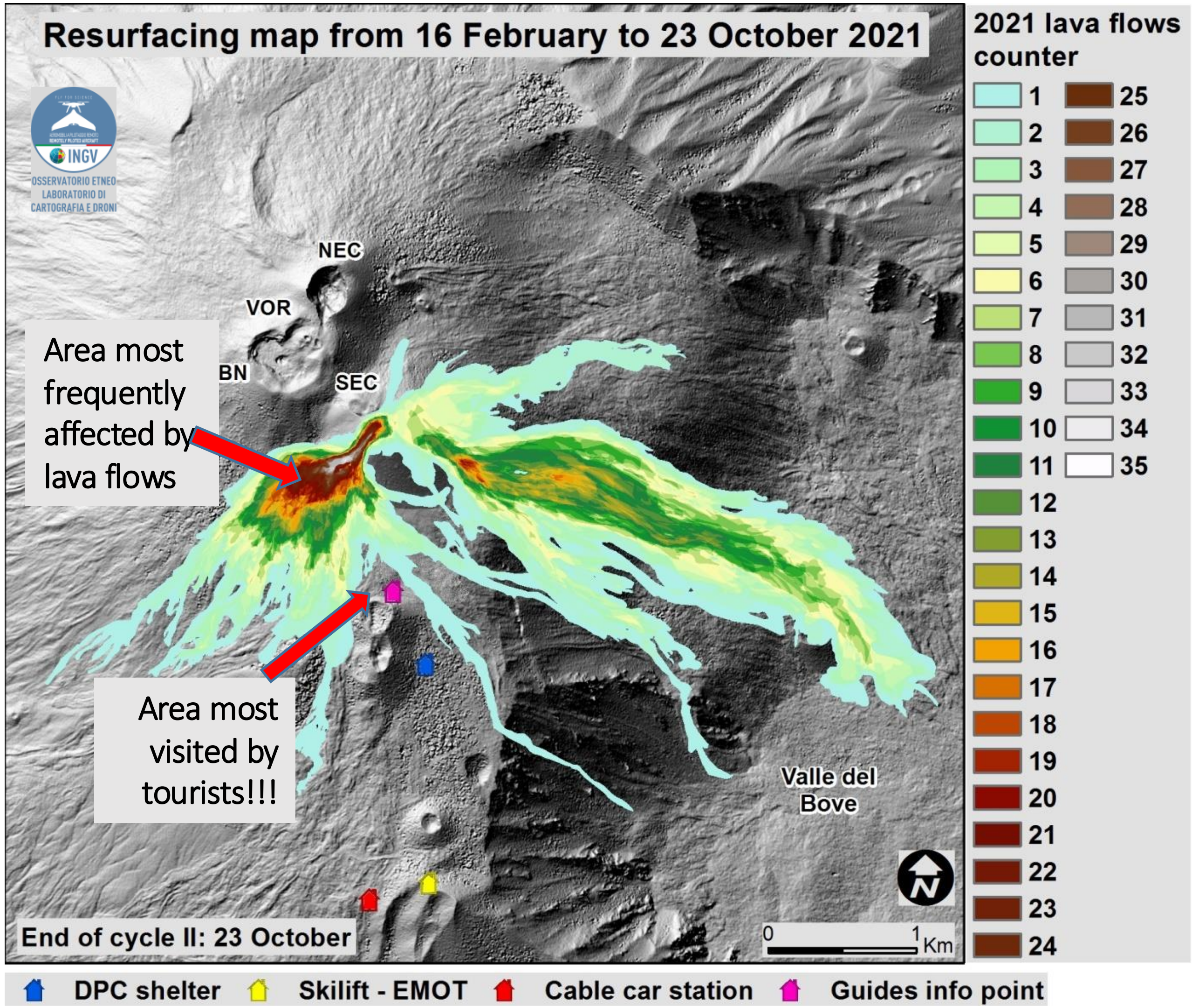


A_{cum}= 2.7 x 10^6 m^2
V_{total}= 29 x 10^6 m^3
Av thick= 10.7 m

Conclusions

- synergistic analysis of different remote sensing data → crucial for mapping **frequent** eruptive events, as observed at Etna in 2021;
- timely mapping of each lava flow and measuring of volcanological parameters→ pivotal to promptly release to the Italian Civil Protection Department, data necessary for the assessment of the related land impact and hazard;
- quantification of the erupted magma → improves the knowledge of short and long term volcanic behaviour;



These data are useful

- as input and checking data for numerical modelling of lava flow
- for hazard evaluation