Remote Sensing techniques to enhance early-warning ground monitoring networks management

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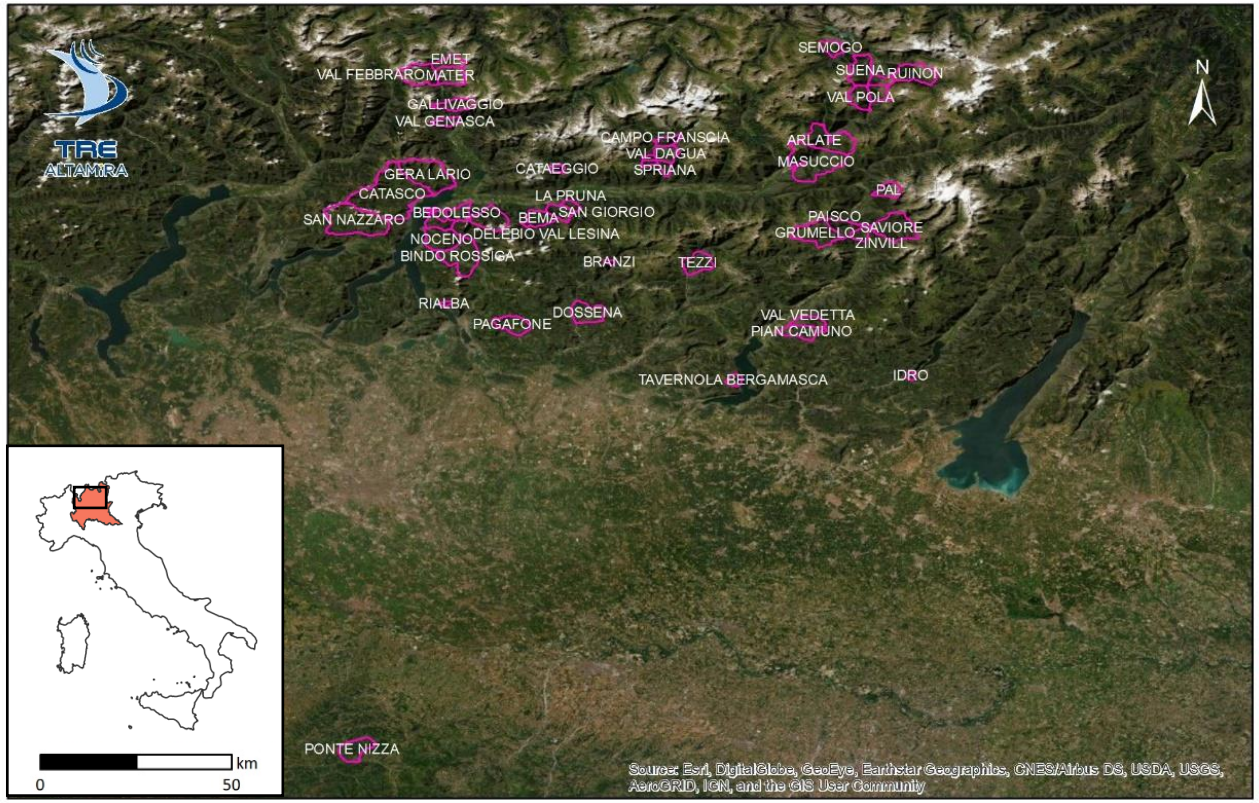
Landslides in Lombardy Region

- Slope instabilities with different dimensions, kinematics, and evolution mechanisms, including different types of movement, going from small scale rockfalls to deep seated gravitational deformations affecting entire slopes
- Currently monitored by the ARPA CMG (Geological Monitoring Center) in Lombardy Region
- CMG is dealing with 45 landslides monitoring networks. Among these, 33 of them are set-up with real-time data transmission.



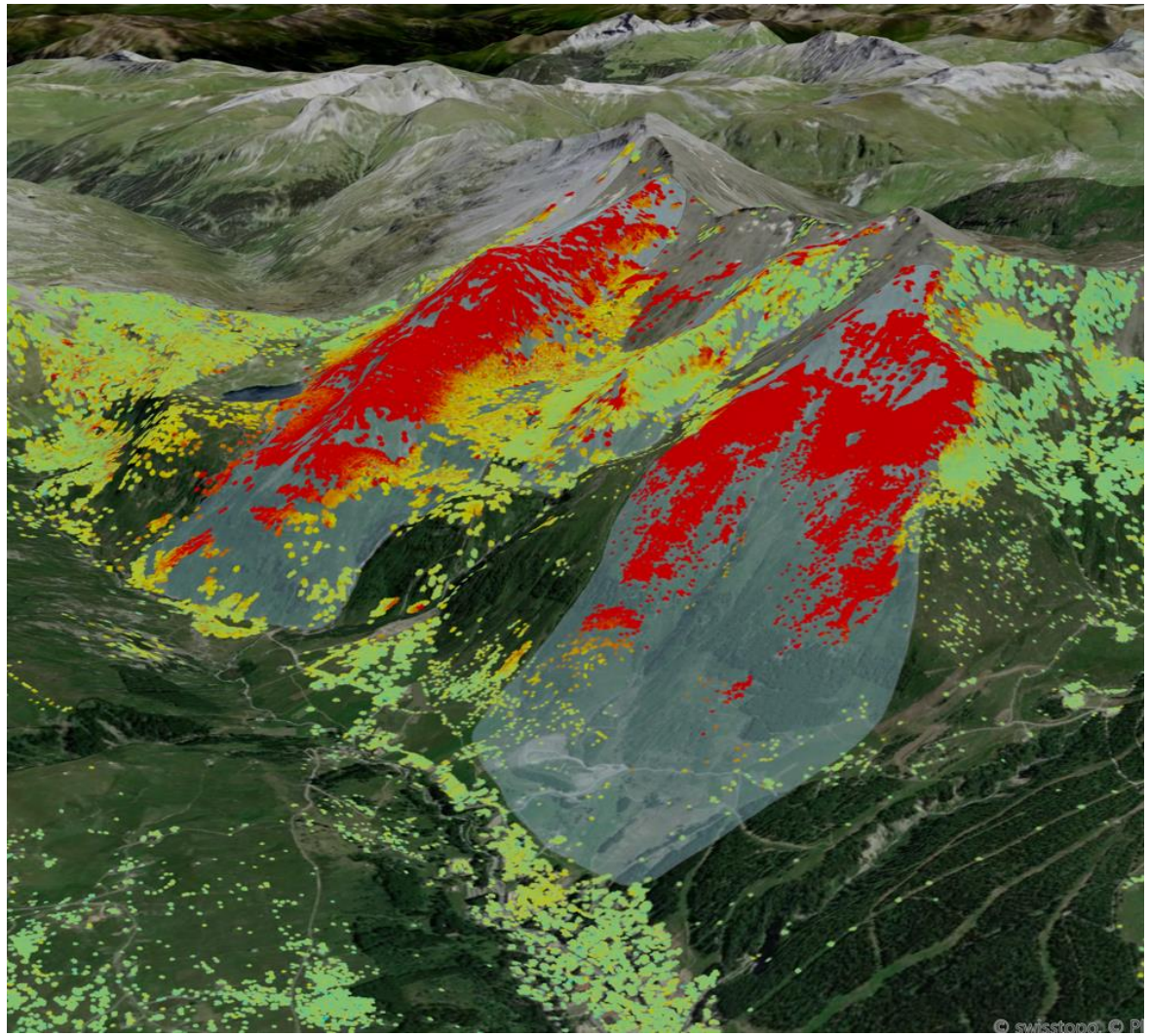
Why Remote Sensing techniques?

We explored the capabilities of InSAR techniques to:

- **Characterize** and **mapping** the landslide areas
- **Improve the ground monitoring network design** (Are we missing something? Can we better design the ground monitoring network?)
- **Integrate remote sensing and ground monitoring data**

InSAR Challenges in alpine areas:

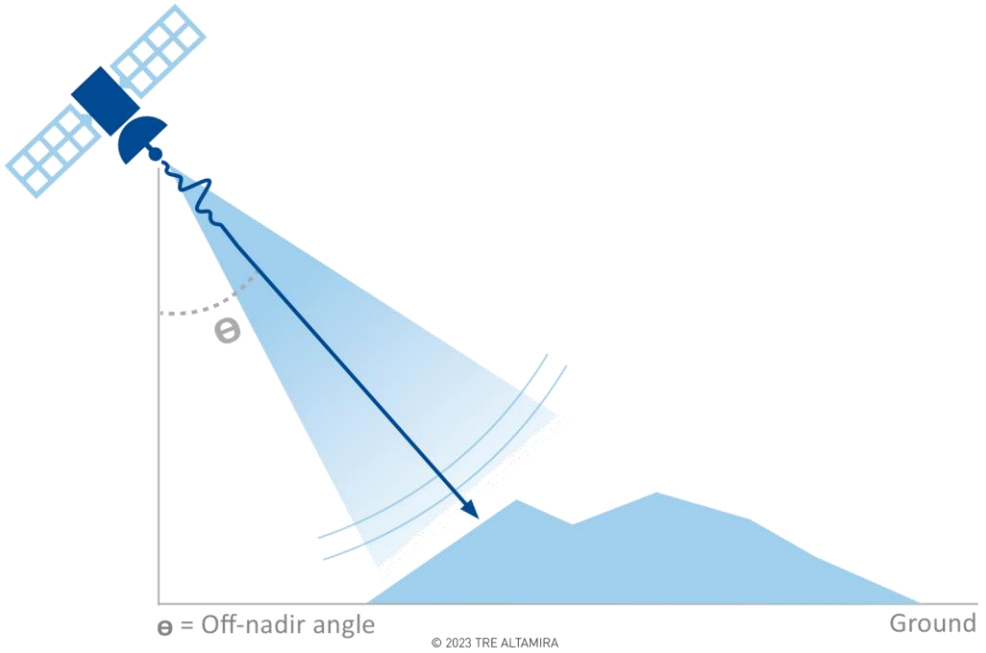
- Large differences in elevation within the same area
- Slope orientation
- Vegetation
- Presence of snow in the winter season at higher altitudes



Datasets

COSMO – SkyMed (CSK) + COSMO – SkyMed Second Generation (CSG)

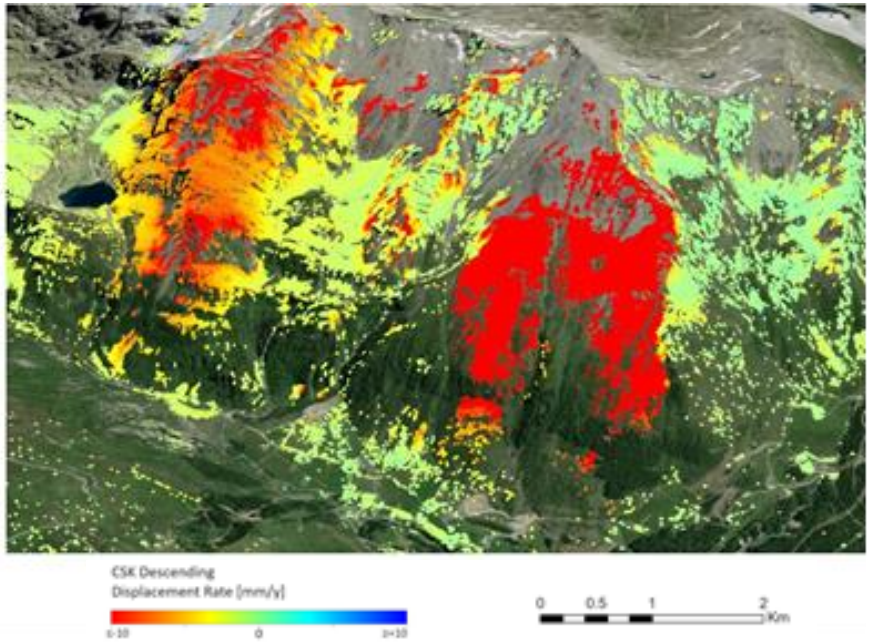
- Ascending and Descending datasets
- 2D
- Resolution: 3 x 3 m
- Nominal revisiting time: 16 days
- X-band (λ≈3.12 cm)
- Time period: January 2010 – November 2022
- Number of images varying between 83 and 223 (depending on area and geometry)



- CSK constellation missing acquisitions
- 18 January 2021: COSMO-SkyMed Second Generation (CSG) became operational
- CSK SqueeSAR® results were compared with Sentinel (SNT) and ALOS-2 (ALS) data processed over similar areas in the same period and integrated with ground monitoring findings.

InSAR Results

- Coverage: more than 3,000 MP/Km^2 in each geometry, despite the well-known challenges for SAR-Interferometry in alpine environments
- The high density of the MPs allows a very detailed overview of the spatial distribution of the displacements, useful both for the **definition of the perimeter of the main landslide** bodies and for the **identification of secondary nested phenomena** and of sectors with different evolutions and state of activity within the same instability phenomenon



Cresta di Emet DSGSD:

- Deformations mainly accommodated by the reactivation of NS-directed main fractures (Zonca M., 2018)
- Characteristic appearance, with scarps and counter scarps
- Sectors with different displacement rate
- Probably due to complex kinematics, influenced by structural elements and topography

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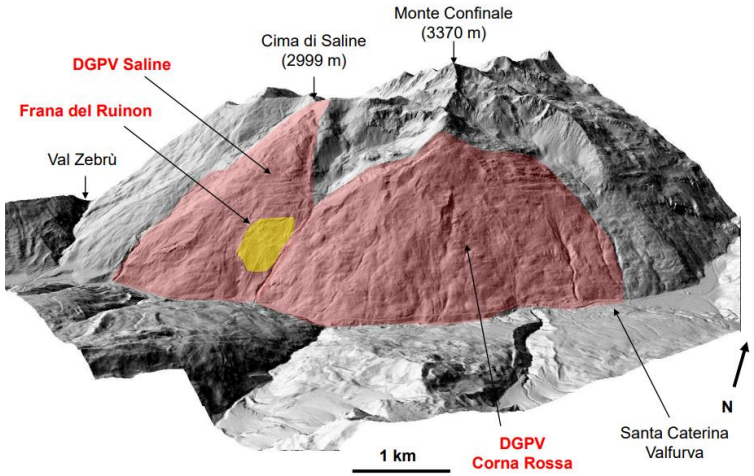
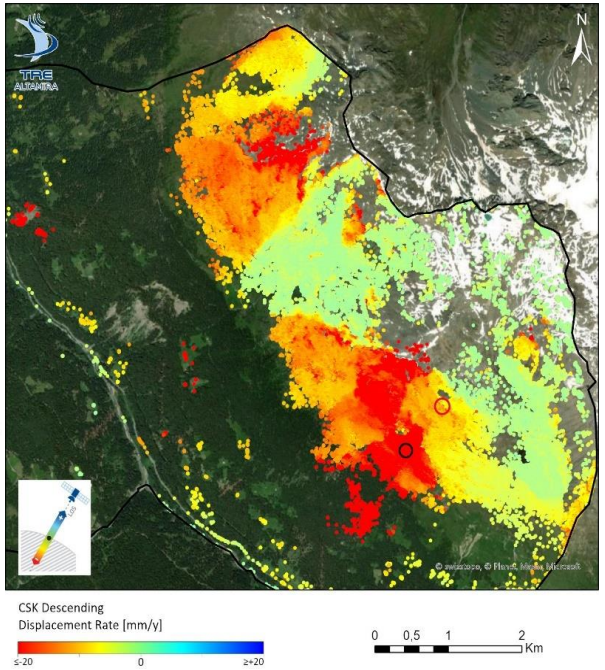
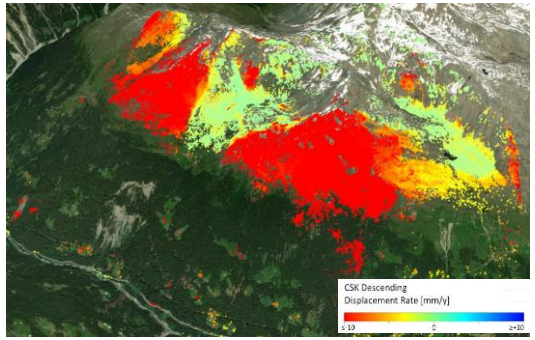
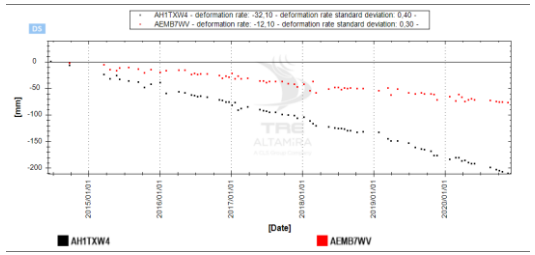


Agliardi et al., 2019







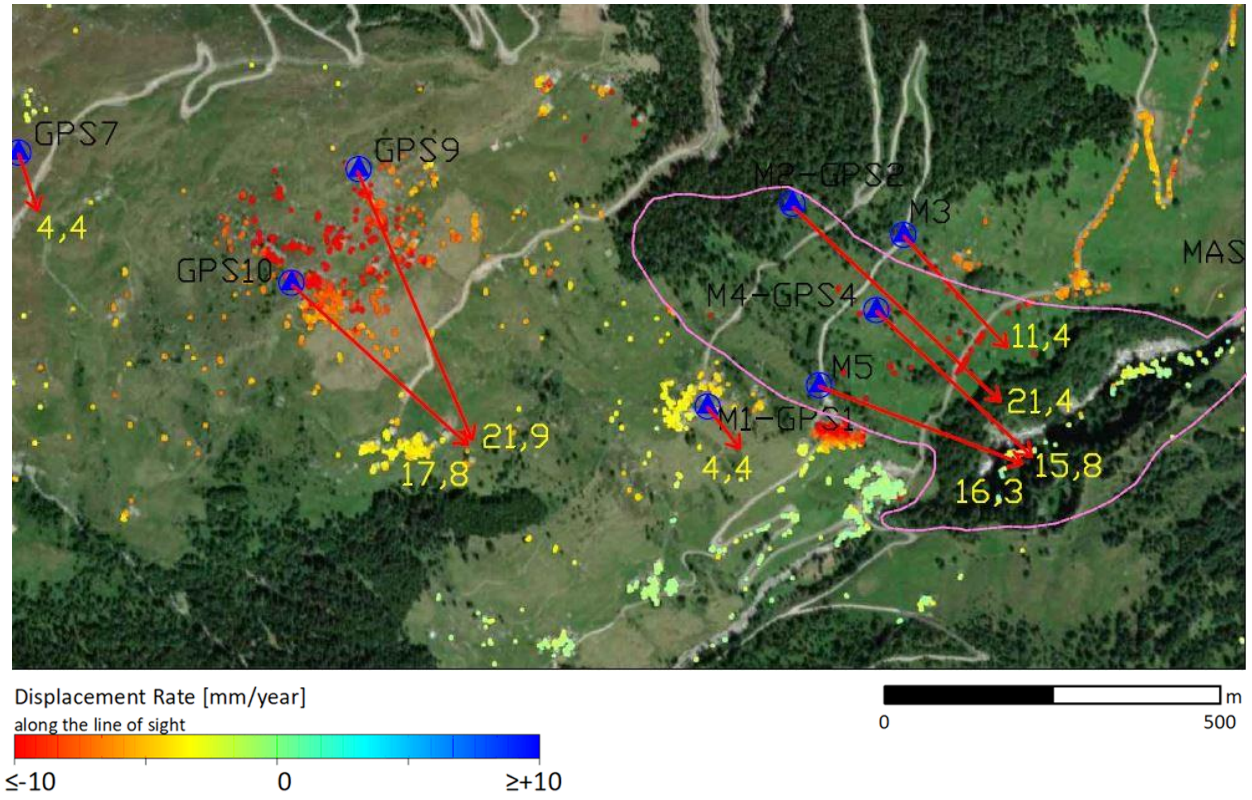
Cresta di Saline – Corna Rossa DSGSD:

- Secondary nested phenomena
- Sectors with different state of activity

Integration with ground-based monitoring networks

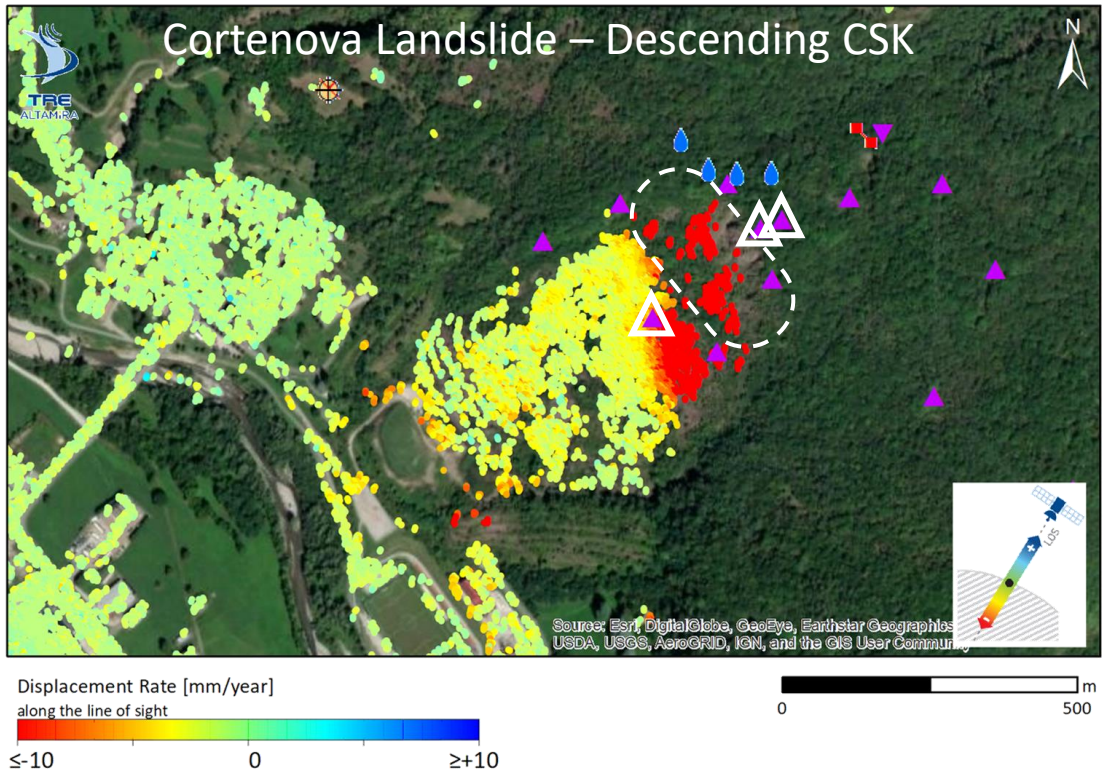
- When available, InSAR and GB monitoring systems showed a good agreement
- InSAR data were used to improve the ground monitoring network design

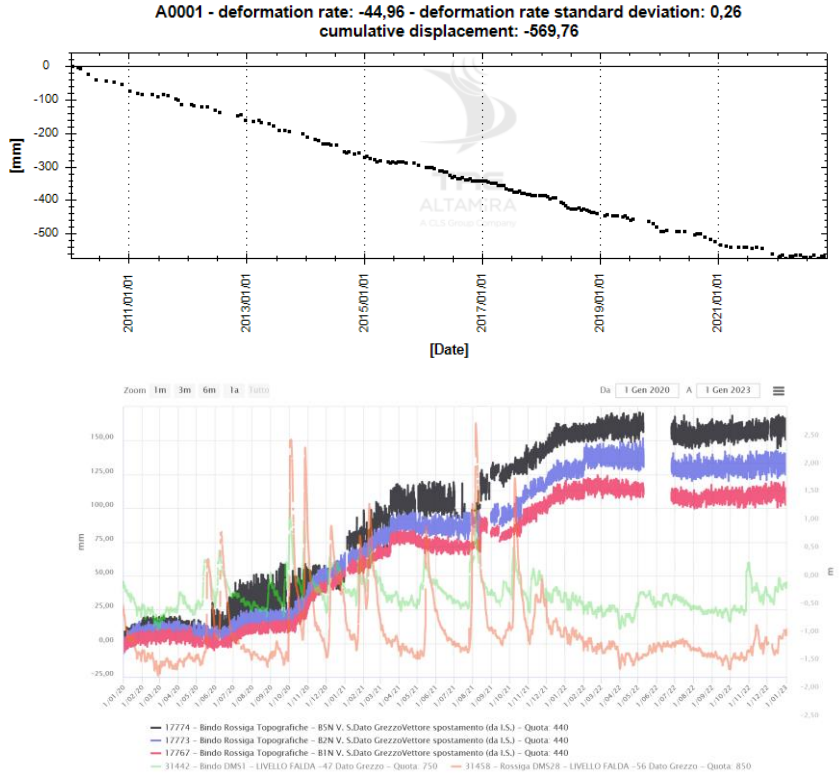
Val Febbraro, Madesimo (SO)



Climatic anomaly 2022

- In 2022 a climatic anomaly, with higher temperatures and less rain and snowfalls, affected all the norther portion of Italy (ARPA Meteo)
- All this led to a lowering of the piezometric water table on the slopes, which for the first 9-10 months of 2022 remained at minimum values without the usual rises caused by spring snowmelt and rainfall
- A general slowdown of landslide displacements was registered both from ground based and intrerferometric data





Which satellite?

COSMO-SkyMed

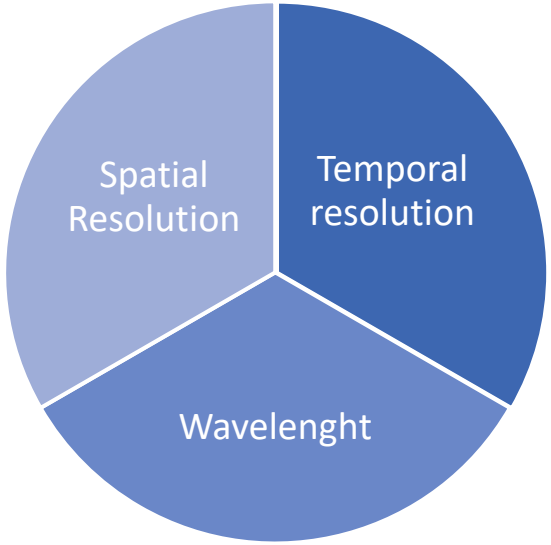
- High measurement density in high reflectivity areas
- Best ability to monitor natural phenomena with velocities below 2-4 cm/year
- Optimal for analysis of infrastructure and buildings
- Low effective time frequency of image acquisition

Sentinel

- High temporal resolution - accurate time series
- Coverage of large areas 250x150 km

ALOS-2

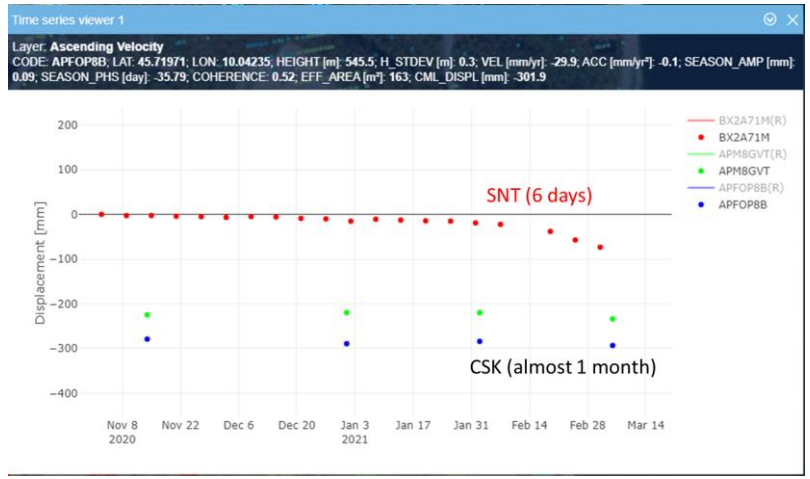
- Better coverage in vegetated areas
- Better ability to monitor natural phenomena with velocities greater than 2-4 cm/year
- Generally, few images available over Italy (higher standard deviations)

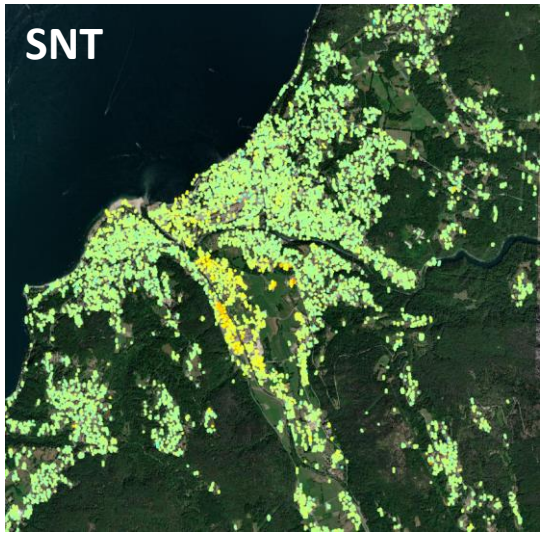


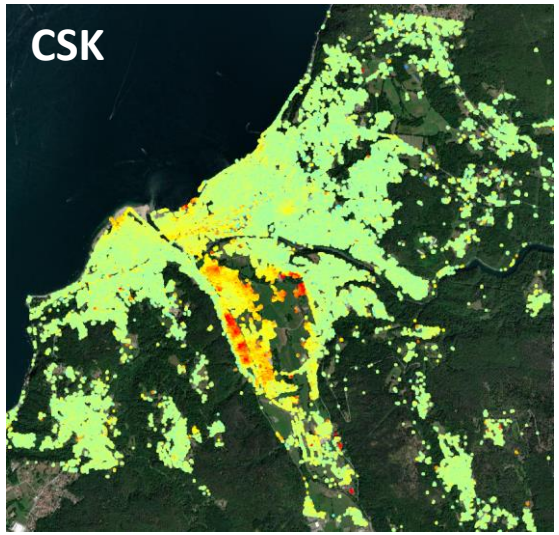
Satellite	Band	Wavelenght [cm]	Spatial Resolution Range x Azimuth [m]	Temporal Resolution [gg]
Sentinel	C	5.93	5 x 20	12 (6)
CSK	X	3.12	3 x 3	16 (8)
ALOS-2	L	23.8	44x57	14

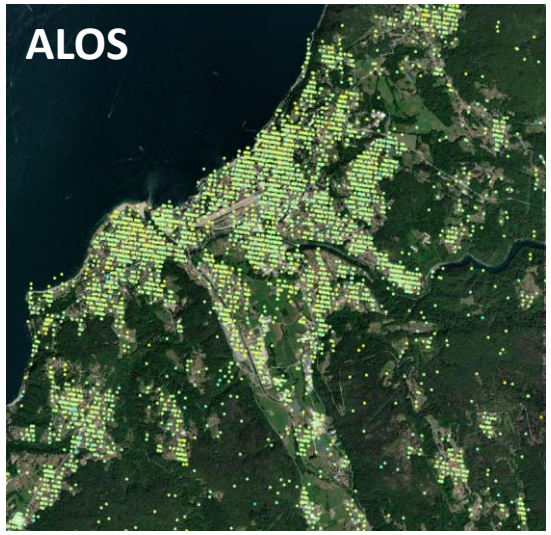
Which satellite?

Tavernola landslide
The low acquisition frequency (approximately 1 image per month in February 2021) prevents the acceleration trend from being followed correctly with CSK, while it is visible in the SNT data, which show a higher frequency (1 image every 6 days)









Final Remarks

- The use of a high-resolution satellite provided a higher density of measurement points than a medium-resolution satellite, such as Sentinel.

- This resulted in **detailed characterization and mapping** of the landslide areas and a discrimination between the more or less active sectors within them (e.g., nested landslides) as well as increased effectiveness when **re-designing ground-based monitoring networks**, which would have been less effective with the use of a medium-resolution satellite.

- The **temporal frequency** of the satellite acquisitions was recognized to have a key role in identifying movement acceleration and avoid underestimations of trend changes.