Telerilevamento Applicato ai Processi di Conoscenza e Gestione del Territorio
13° Workshop Tematico
Bologna 22-23 Settembre 2022

REGIONAL-SCALE LANDSLIDE INVESTIGATION USING CONVENTIONAL TWO-PASS INTERFEROMETRY

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Outline

Rationale, motivation of the work

InSAR processing, methodological notes

Active landslide detection at regional scale

Monitoring landslide activity

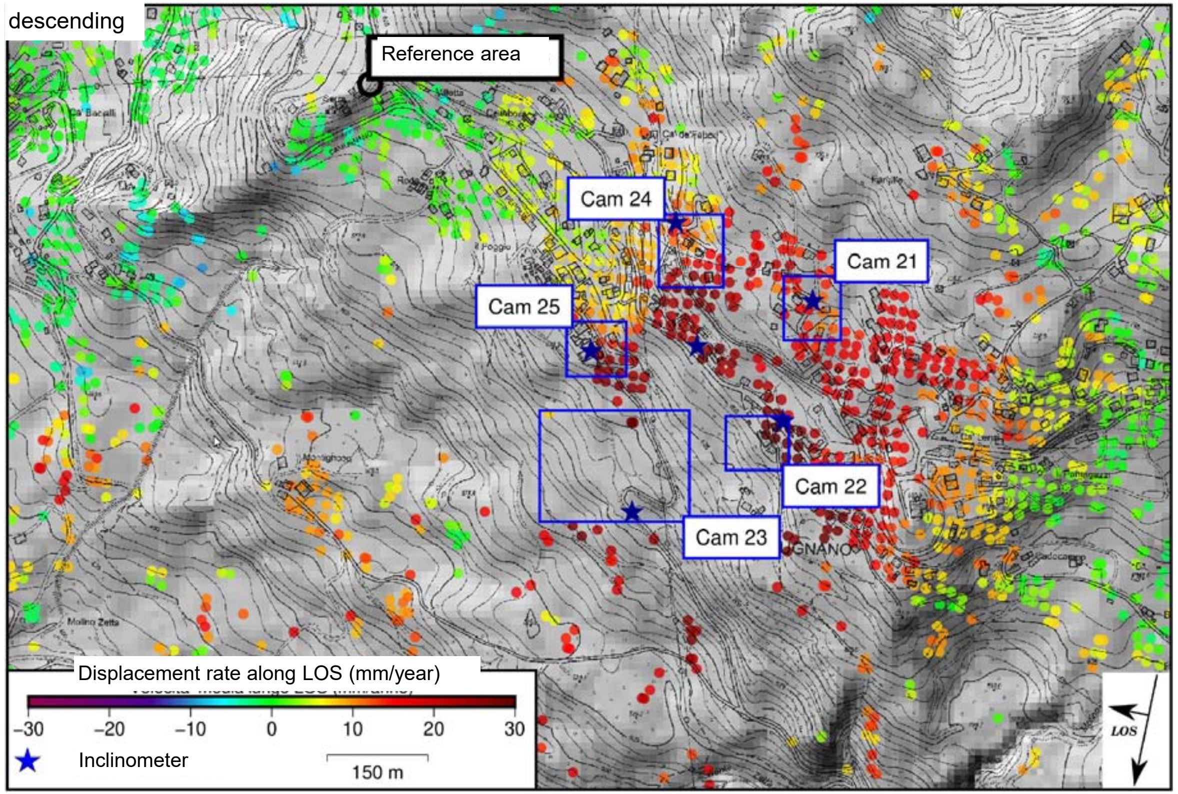
few examples

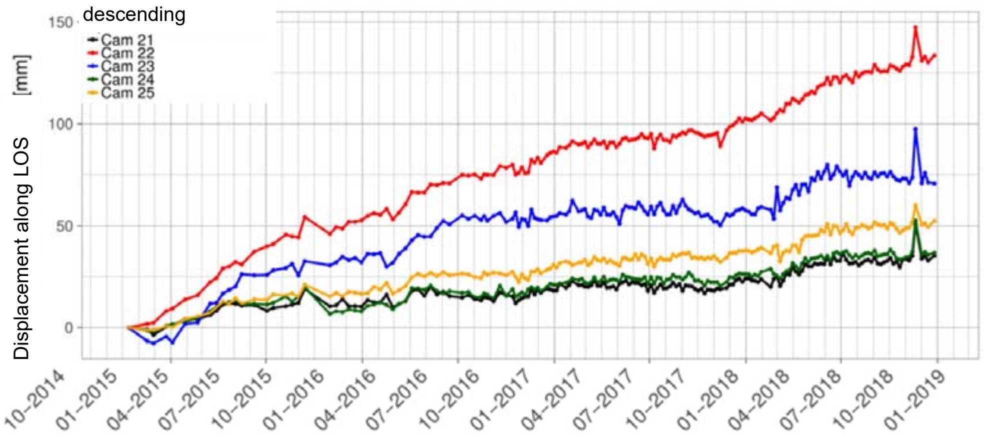
comparison to climate parameters used for territorial early warning

Discussion and Conclusions

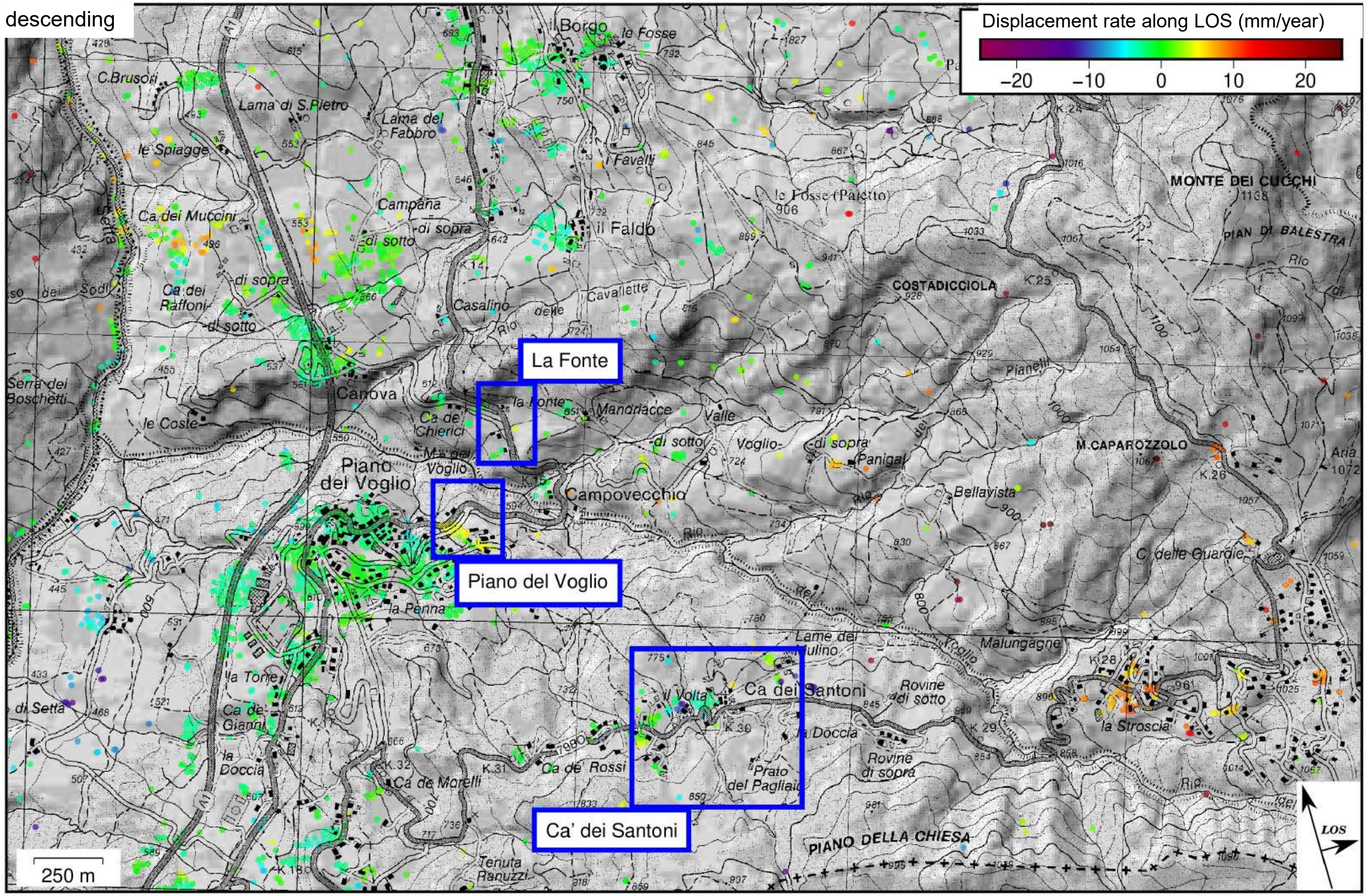
Rationale

The vast majority of InSAR application to landslide is represented by multi-temporal analysis that aim to extract displacement information of **stable / permanent / persistent scatterers**.





Rationale

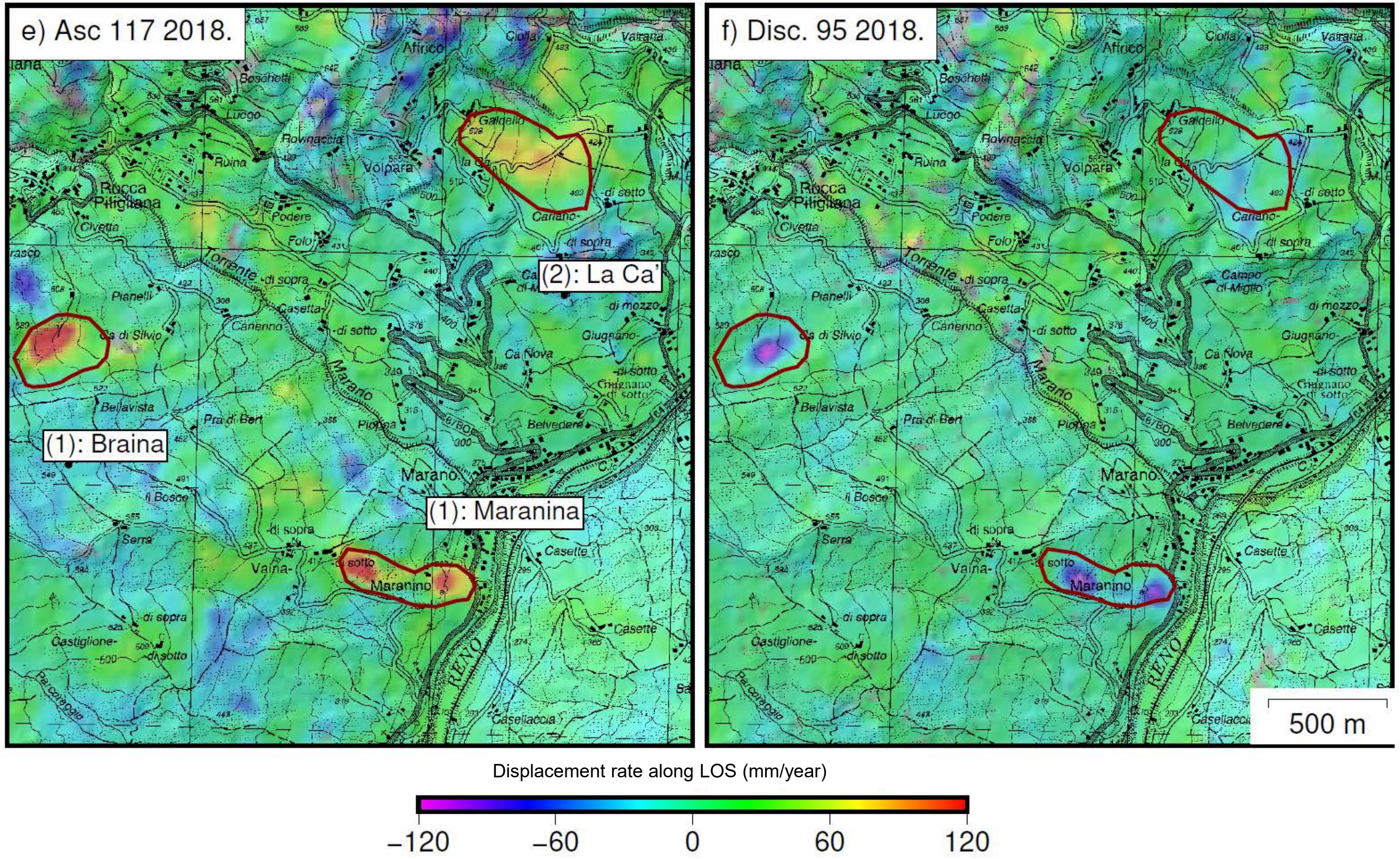


Despite efforts to maximize their number and distribution, **stable scatterers** are mostly found where:-

- man-made structures or rock outcrops are abundant;
- vegetation is scarce or absent;
- slope has favourable orientation;
- velocity is low (< few cms / month).

Rationale

<u>Conventional two-pass interferometry</u> (**Standar InSAR**) gained significance in the last few years because of the availability of SAR images with minimum spatial and temporal baseline to decrease possible sources of decorrelation.



Standard InSAR can be used to maximize the amount of displacement information that can be retrieved from SAR images.

It can be used when:

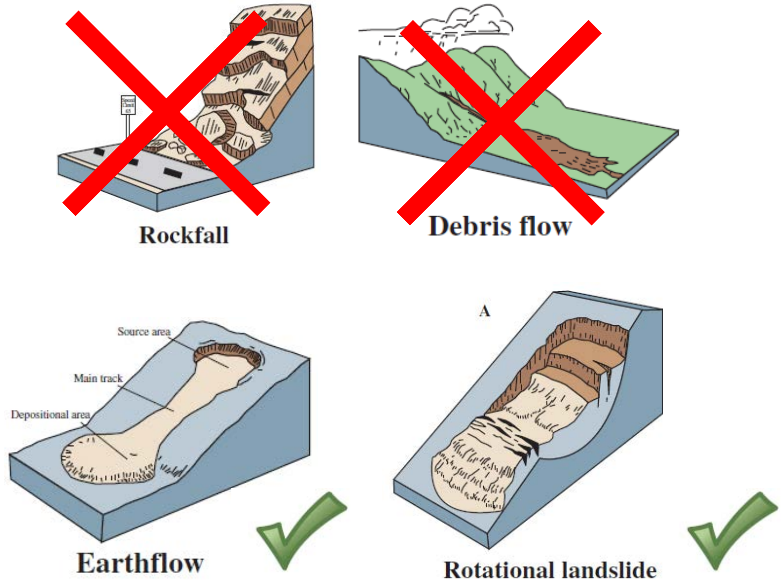
i) the density of stable scatterers is not sufficient to the scope;

ii) to integrate the results of a Multi-temporal InSAR analysis.

Landslides often initiate/develop in rural areas where stable scatterers are scarce or absent.

InSAR and landslides

Type of movement:
rock falls, debris flows and small shallow failures may simply go undetected; movements involving large volumes (e.g., slides, earthflows) can be detected and monitored.



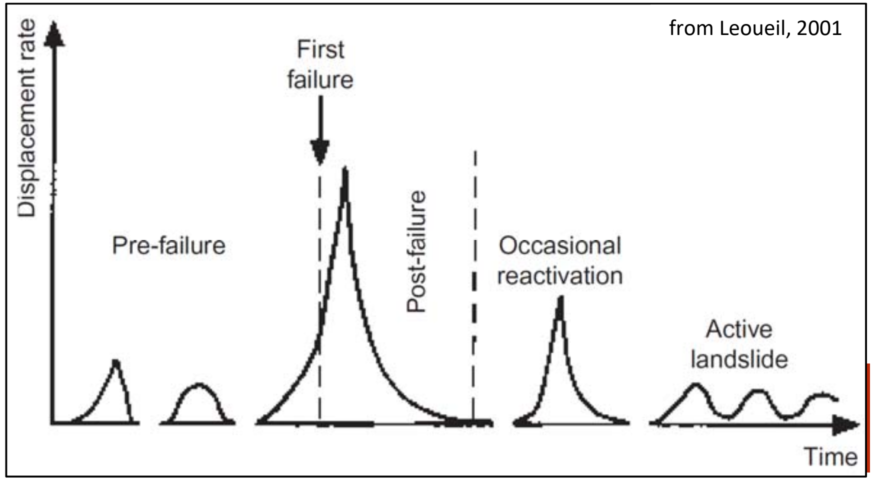
Velocity of movement:
"very slow" to "slow" movements are better detected by InSAR (up to 0.1÷1 m/yr)

Landslides may continue moving and experience periodic accelerations for thousands of years.

Cycles of **rainfall-induced acceleration** are common.

Failure episodes may be too fast for InSAR detection,

pre-failure and **post-failure stages** can be monitored.



Landsliding in the Umbria region

Area: 8456 km^2

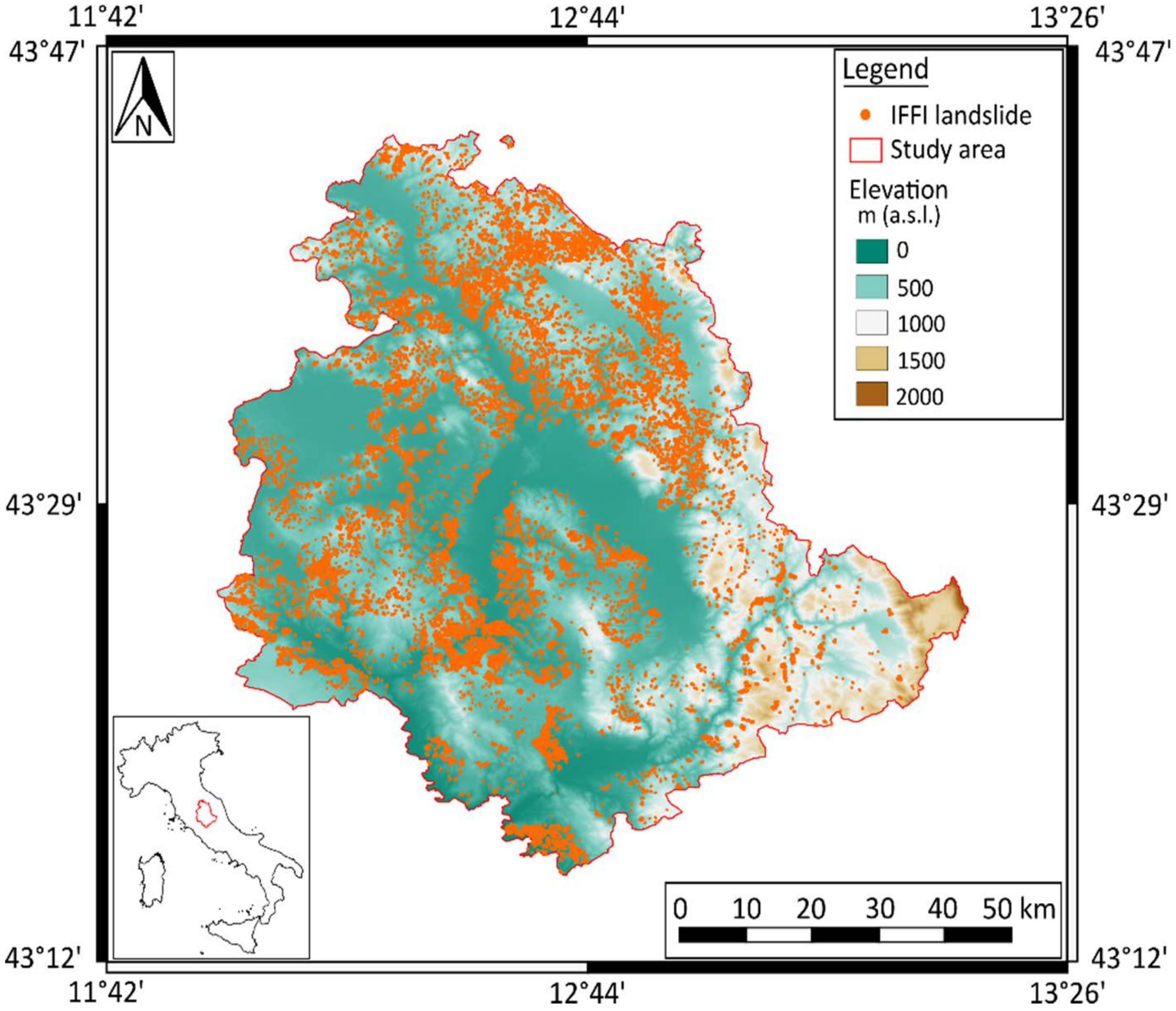
Elevation range: 50 to 2436 m a.s.l.

Geology: tertiary flysch, Pliocene marine and continental facies, limestones, …

Land use: Agriculture/arable land 54%, forest 32%, urban areas about 5%.

Landslides: all municipalities are exposed to some risk, landslide deposits cover about 9% of the area.

According to the national inventory IFFI, 12477 mapped landslides (70% dormant)

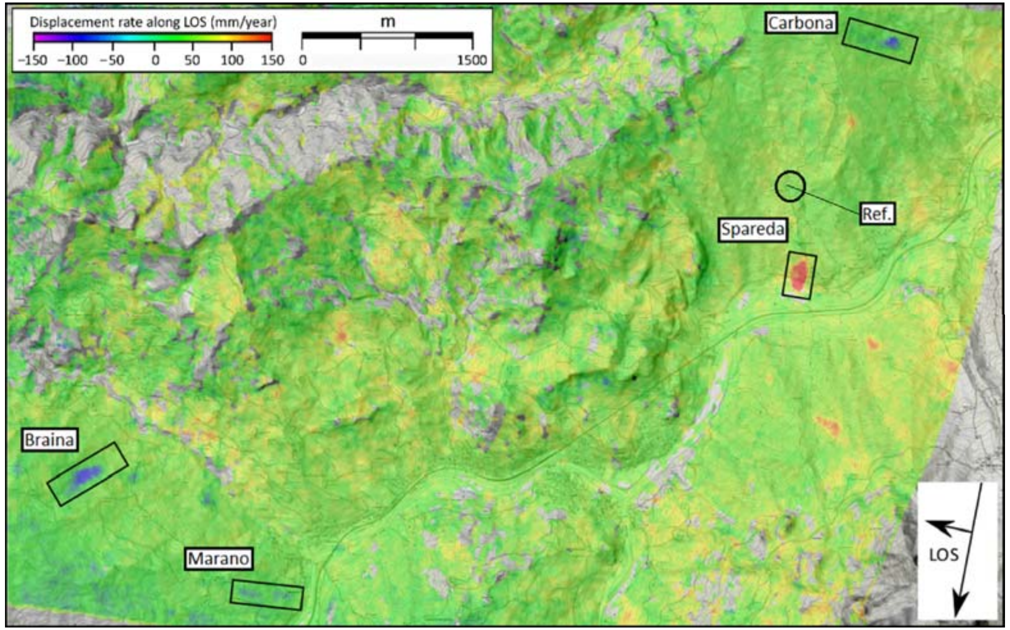


Methodological notes

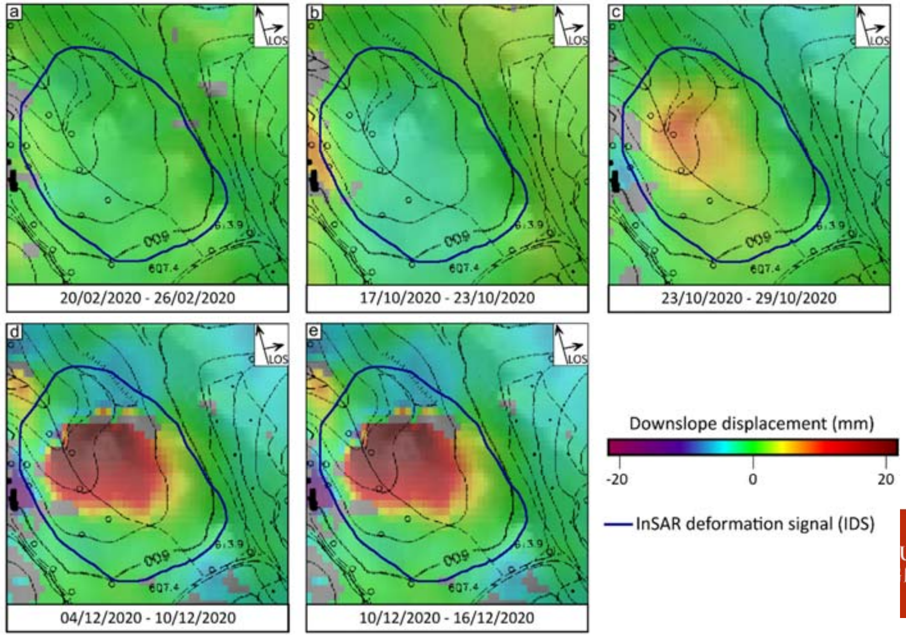
conventional two-pass interferometry, Sentinel 1 A/B SAR images (C-band, 6 days repeat time)
October 2019 to January 2021, two descending and two ascending orbit

1120 interferograms, 6÷24 days ➔ highlight features moving at a rate sufficient to observe deformation in a short time span, yet slow enough to avoid loss in radar coherence.

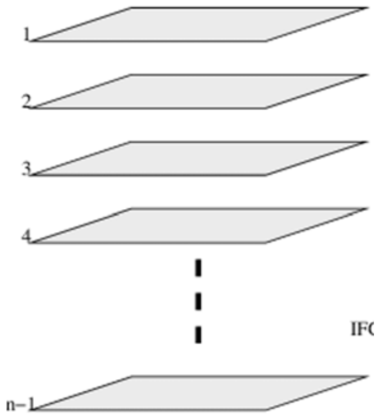
in order to DETECT and MAP active landslides, we use **stacked interferograms**



in order to explore the POTENTIAL IN MONITORING, we select and interpret **6-days interferograms**



Methodology: detection of active landslides

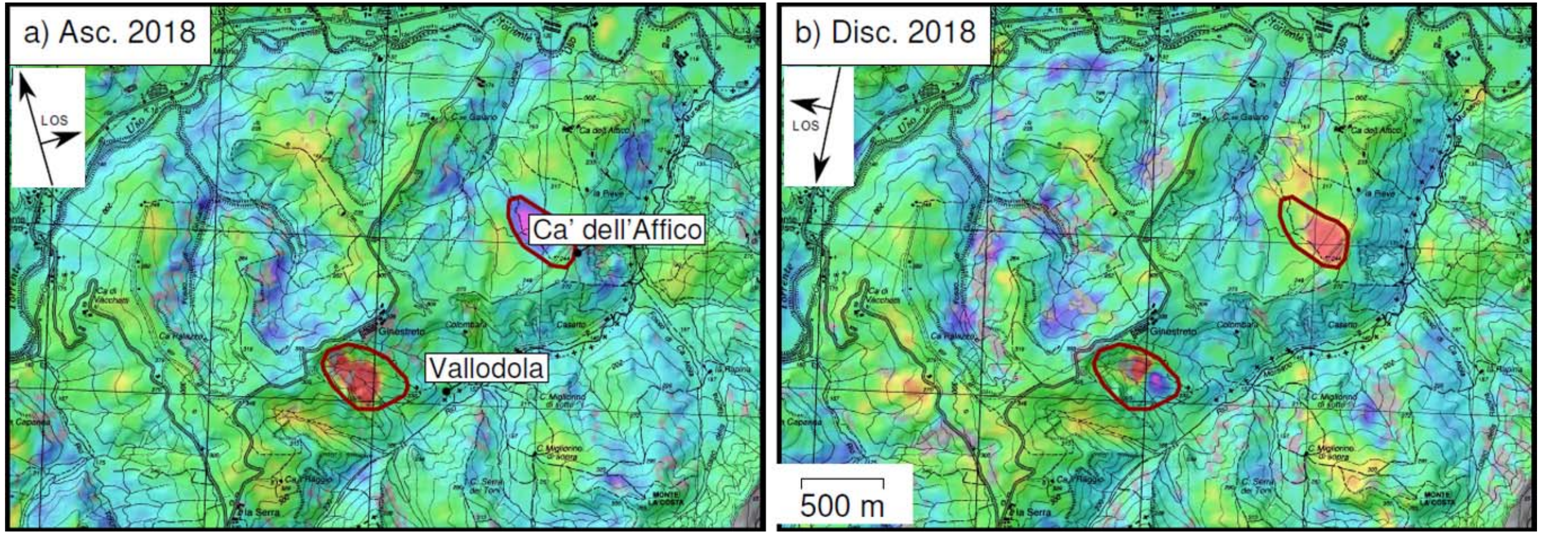


Stacking interferograms (time-averaged deformation) increases the signal-to-noise ratio and highlights deforming features.

Identification and mapping of InSAR Deformation Signals, likely caused by landsliding (IDS)

Typically, IDS show a sign inversion of the movements in the ascending and descending orbits, which is consistent with a downslope deformation, especially when the slope gradient is gentle and the along-slope displacement dominant.

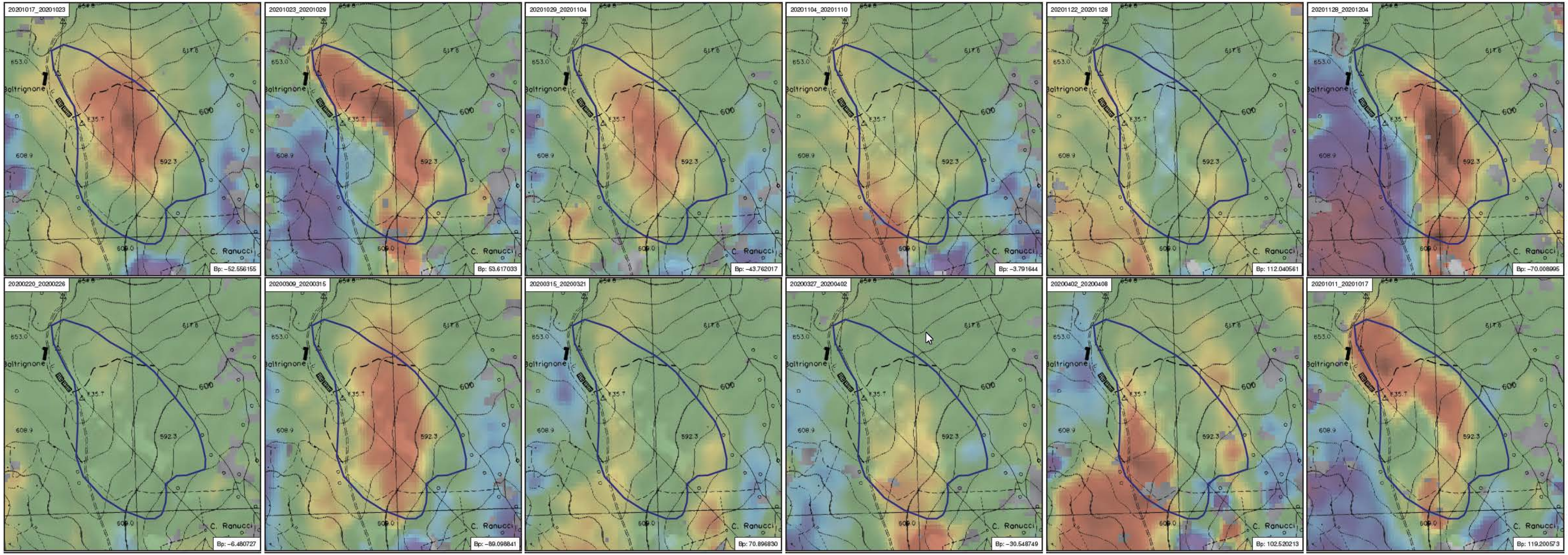
Overall, the standard InSAR workflow, is complex, time-consuming and includes a subjective component (expert judgement).



Methodology: velocity time-series of selected deformation signals

13 deformation signals are selected and their evolution analyzed through single 6-DAYS INTERFEROGRAMS

We use ascending or descending orbit, depending on their quality and convert LOS displacement in downslope displacement.
Highly decorrelated interferograms are discarded based on visual inspection (only about half of them is usable).



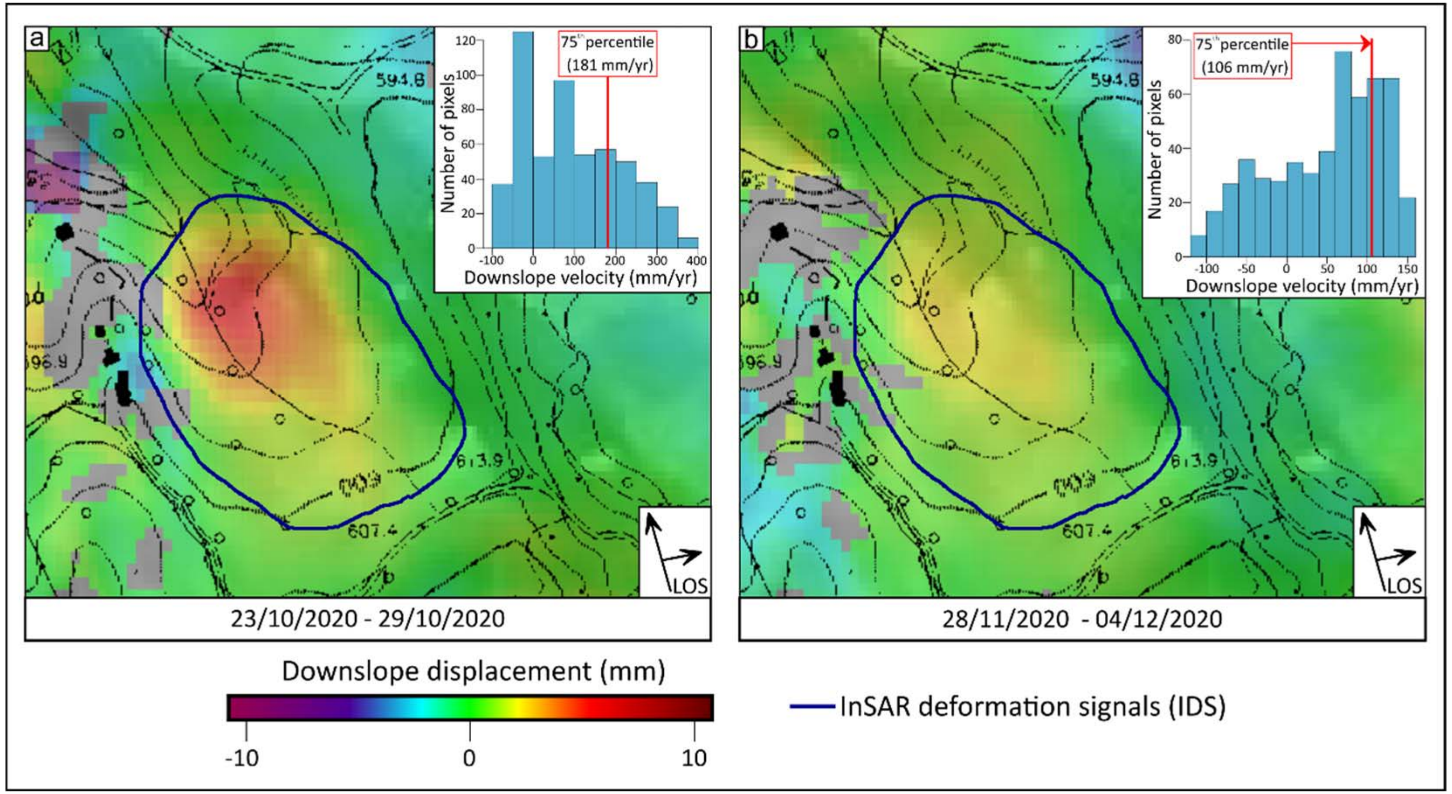
Methodology: velocity time-series and state of activity

We use the 75th percentile of the displacement rate measured within the IDS perimeter to estimate the landslide velocity.

We distinguish:

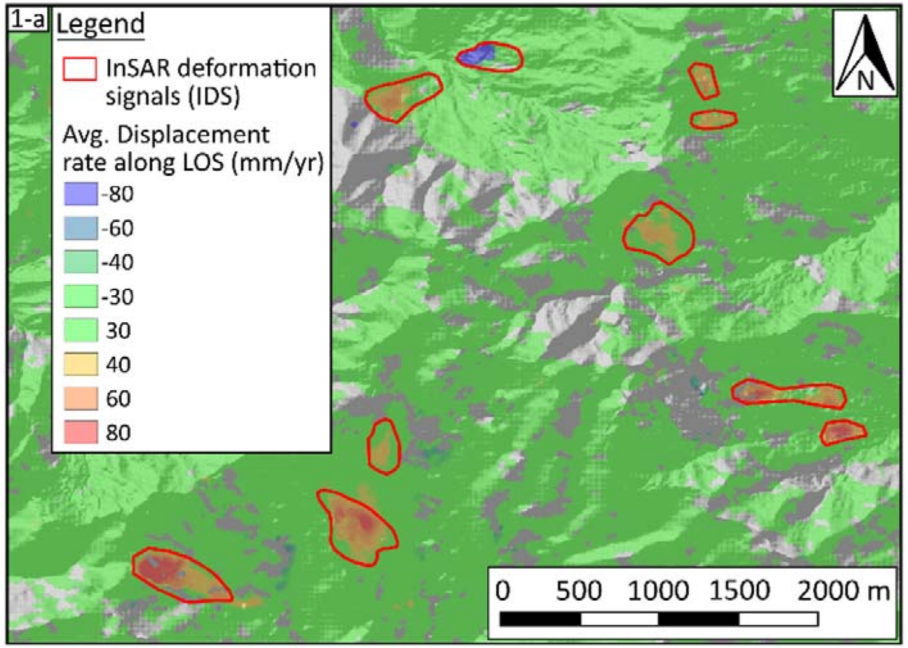
"**active state**" ➔ deformation signal clearly recognizable

"**inactive state**" ➔ deformation signal weak or absent.



Results: detection of actively moving landslides

Interferometric Stacks show good coverage with decorrelated areas (i.e., grey areas) mostly located along steep, heavily vegetated slopes



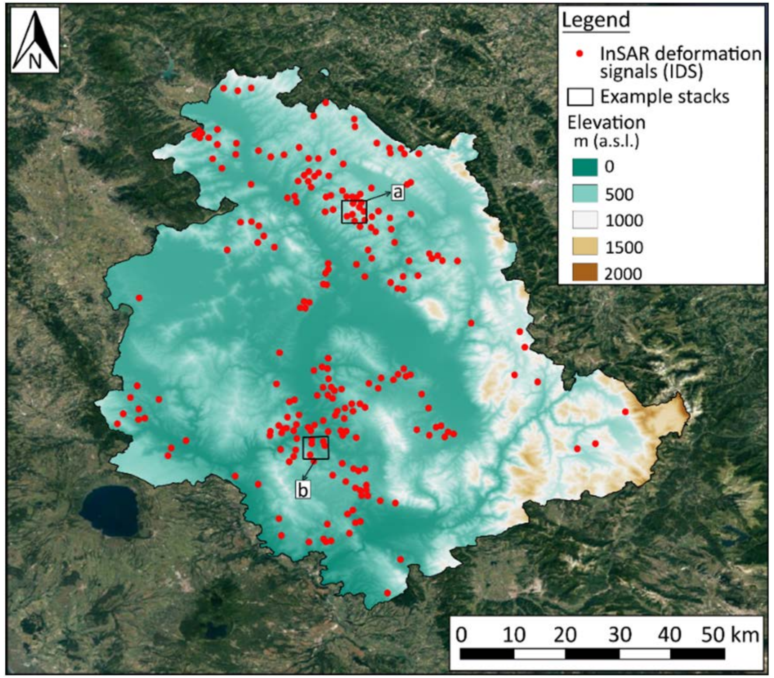
252 InSAR Deformation Signals identified

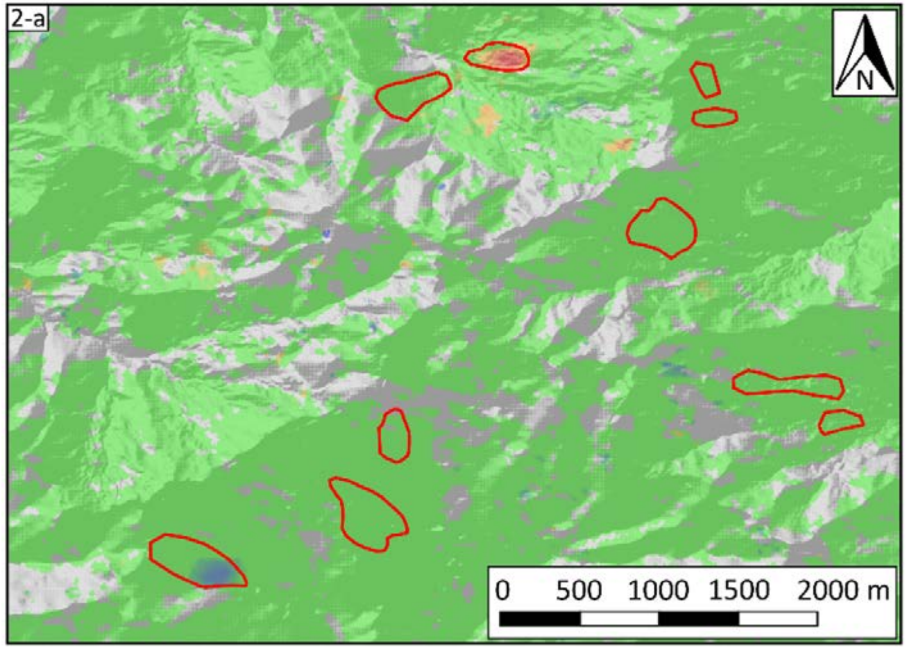
166 recognized in mapped landslide deposits

active landslides

86 located along slopes

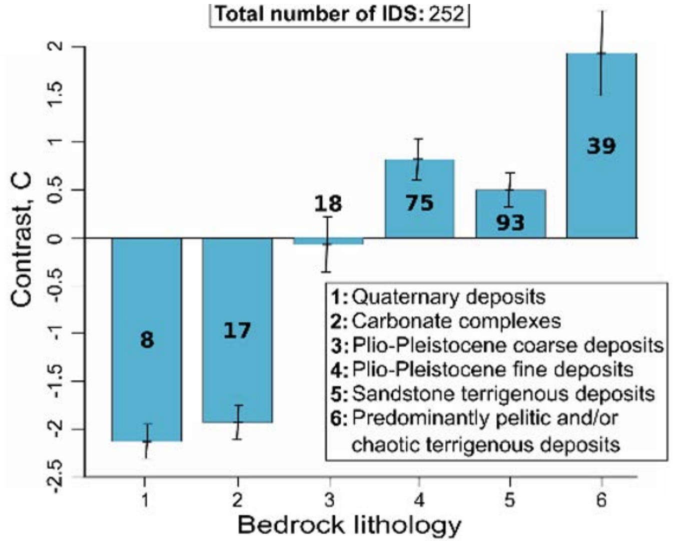
incipient slope failures or reactivation of undetected landslides



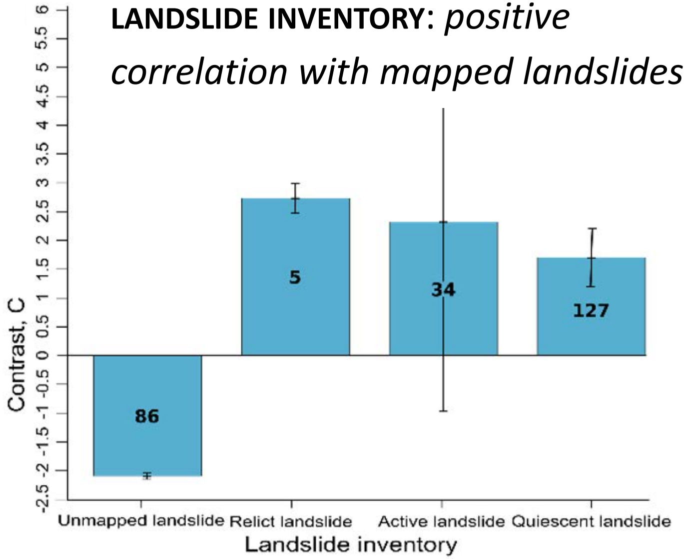


Spatial distribution of IDSs against control elements

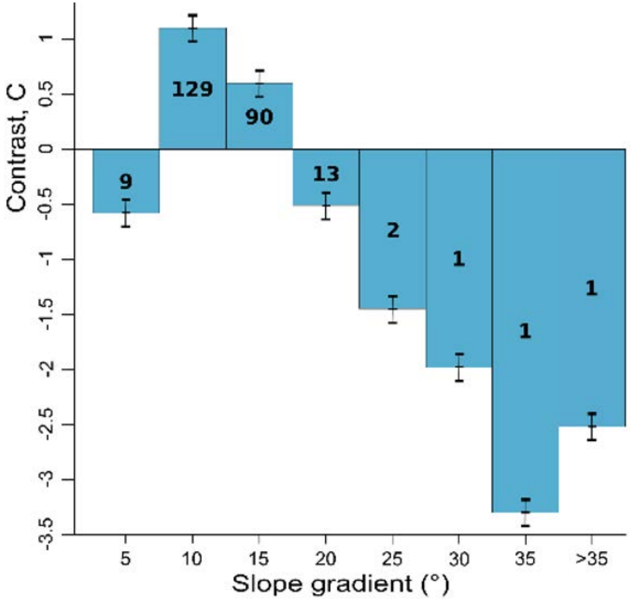
BEDROCK LITHOLOGY: *positive correlation with pelitic/chaotic terrigenous deposits and plio/pleistocene fine deposits*



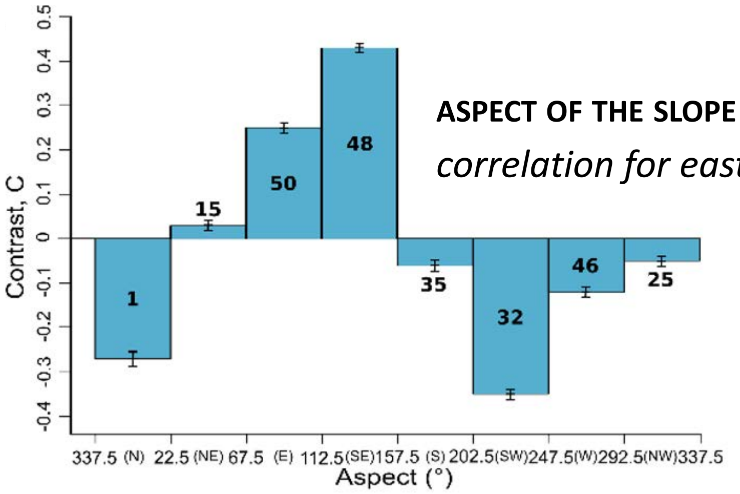
LANDSLIDE INVENTORY: *positive correlation with mapped landslides*



SLOPE GRADIENTS: *signals more abundant along gentle slope (7.5° to 17.5°)*



ASPECT OF THE SLOPE: *positive correlation for east-facing slopes*

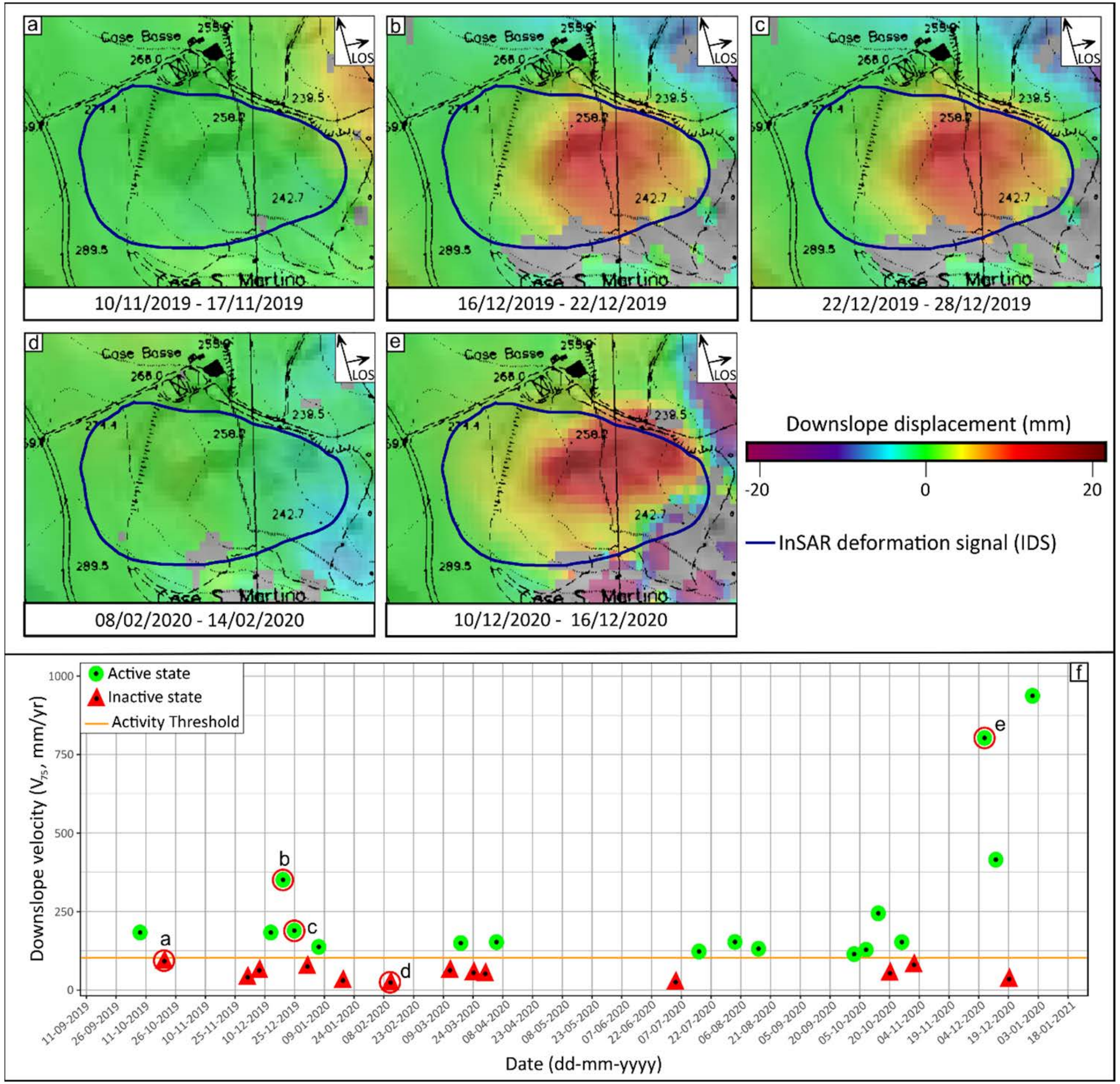


Monitoring the evolution through single interferograms

Example, Montanaldo
fine deposits of Plio-Pleistocene age
gently dipping slope (9.2°) facing East

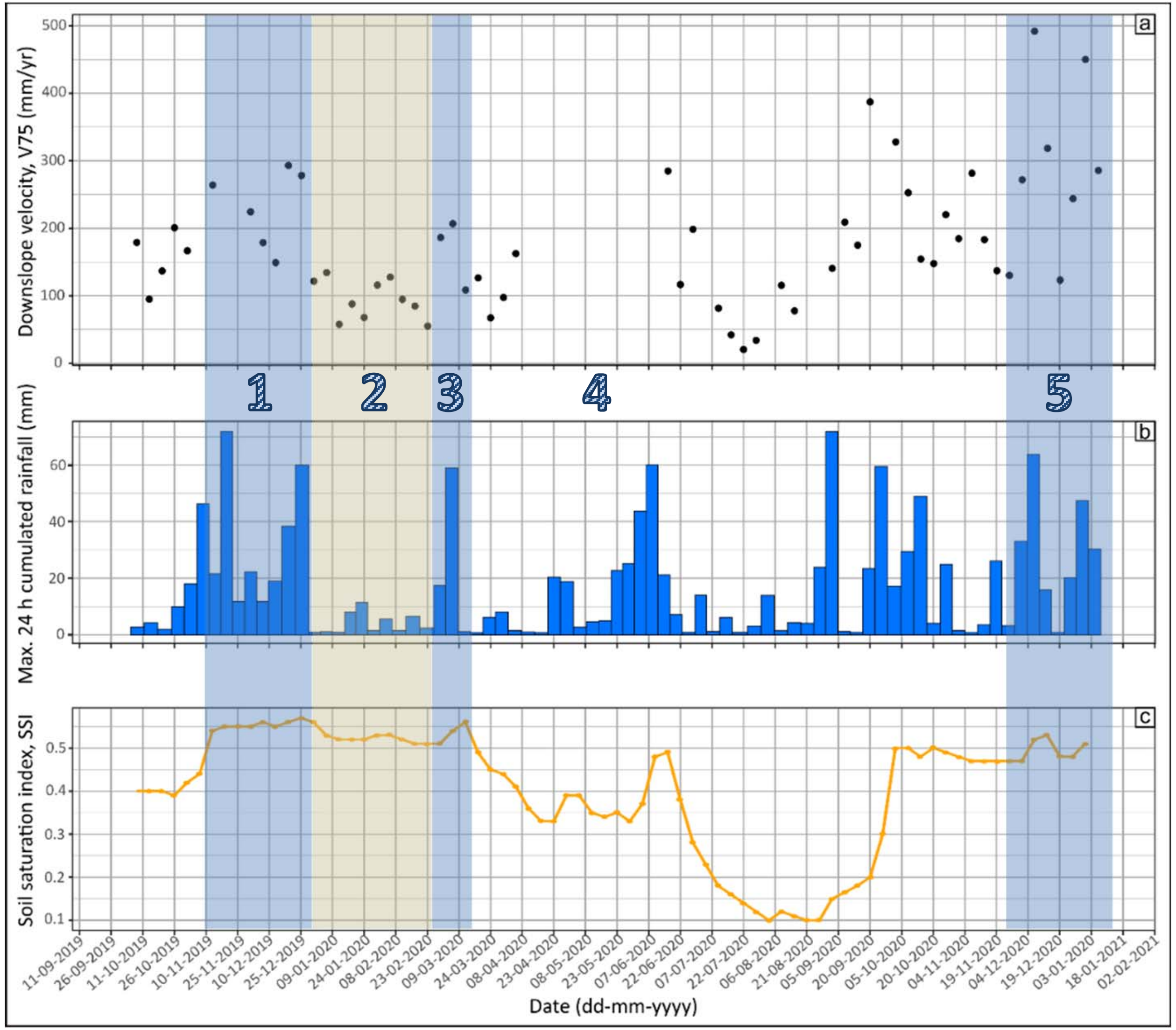
V_{75} values are used to describe
the landslide time-series
and classify its state of activy

slow movements with accelerations in December 2019 and 2020, when estimated velocities peak at 800 mm/yr



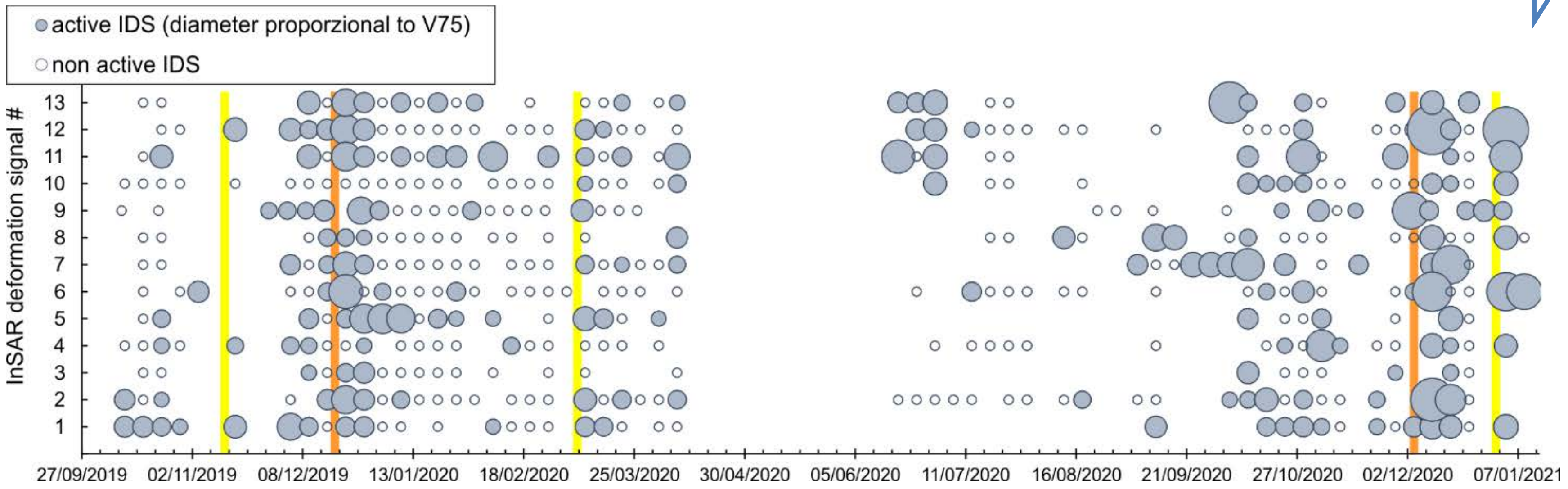
Mean evolutionary trend

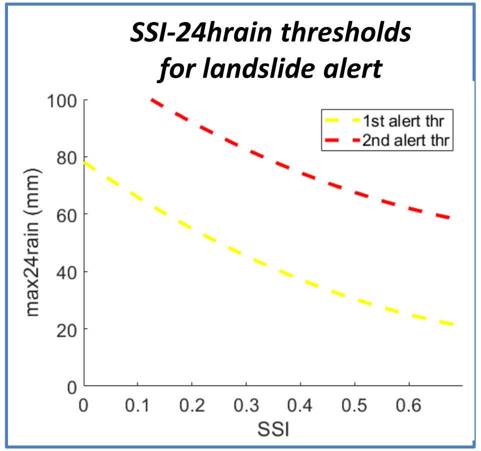
1. November-December 2019, rainfalls and soil saturation, mean V_{75} increase up to 300 mm/yr, following intense mid-December rainfalls.
2. January and February 2020, dry – velocity decrease.
3. March 2020, saturation still high, rainfalls cause a clear acceleration.
4. Spring and Summer seasons, highly decorrelated interferograms due to vegetation growth, uncertain appreciation of June's rain effect.
5. December 2020, saturation and rainfall peaks well correlated with acceleration ($V_{75} \approx 500$ mm/yr).



Landslide activity and landslide territorial alerts

distribution of active and inactive landslides compared to 1st and 2nd level landslide alerts issued in Umbria





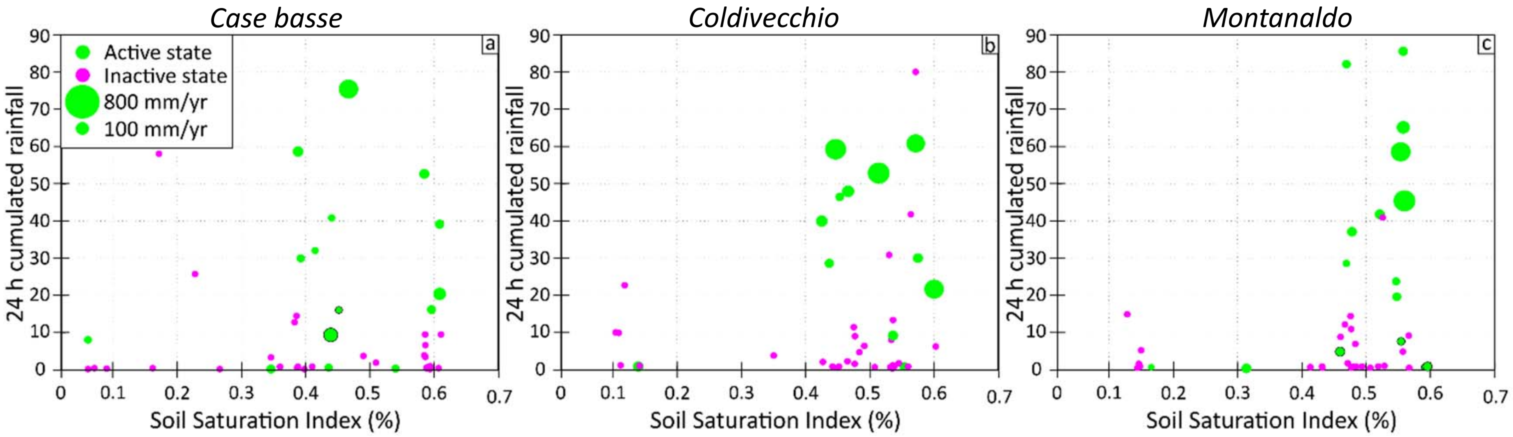
good overall agreement with expections (inherent significance of thresholds, sustained landslide deformation, local anomalies, …)

landslide reactivations/accelerations detected through InSAR can be used as evidences to validate territorial alert thresholds?

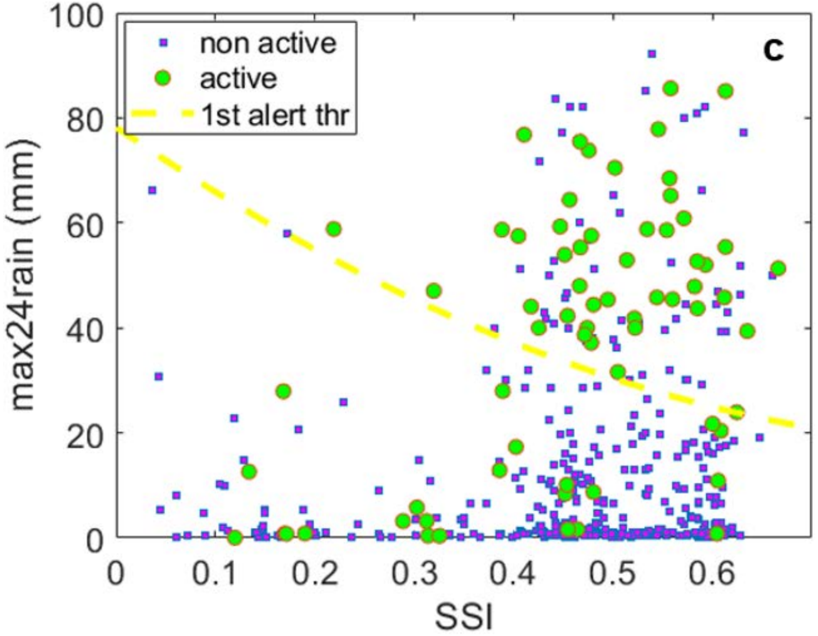
Landslide activity and landslide thresholds (SSI-24h rain space)

Active and inactive IDS states show a good degree of separation in the SSI – 24-hours rain space

single cases



aggregated data



threshold of the Umbria LEWS is capable of identifying the climatic conditions associated to landslide activity detected through InSAR

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Conclusions

landslide detection and mapping

standard InSAR allows the detection of slow slope movements over large areas

compared to multi-temporal InSAR: better territorial coverage, higher displacement rates, lower accuracy

good price / quality ratio, efficient way to update existing landslide inventories and track active phenomena

landslide monitoring

analysis of 6-days interferograms gave encouraging results though interpretation is crucial (automation still a long way off)

the relationship between precipitation and landslide deformation is rather clear

territorial early warning thresholds can expoit remotely-sensed information to refine their calibration

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GRAZIE PER L'ATTENZIONE

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