# Detection and measurement of landslide deformation prior to their failure by satellite radar interferometry.


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# Outline

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***Landsliding in the Northern Apennines of Italy, generalities***

***InSAR processing, methodological notes***

***3 Examples of landslides reactivated last December (2019) and results of our InSAR analysis***

InSAR areal analysis

Site-specific InSAR analysis

*Braina landslide*

*Carbona landslide*

*Spareda landslide*

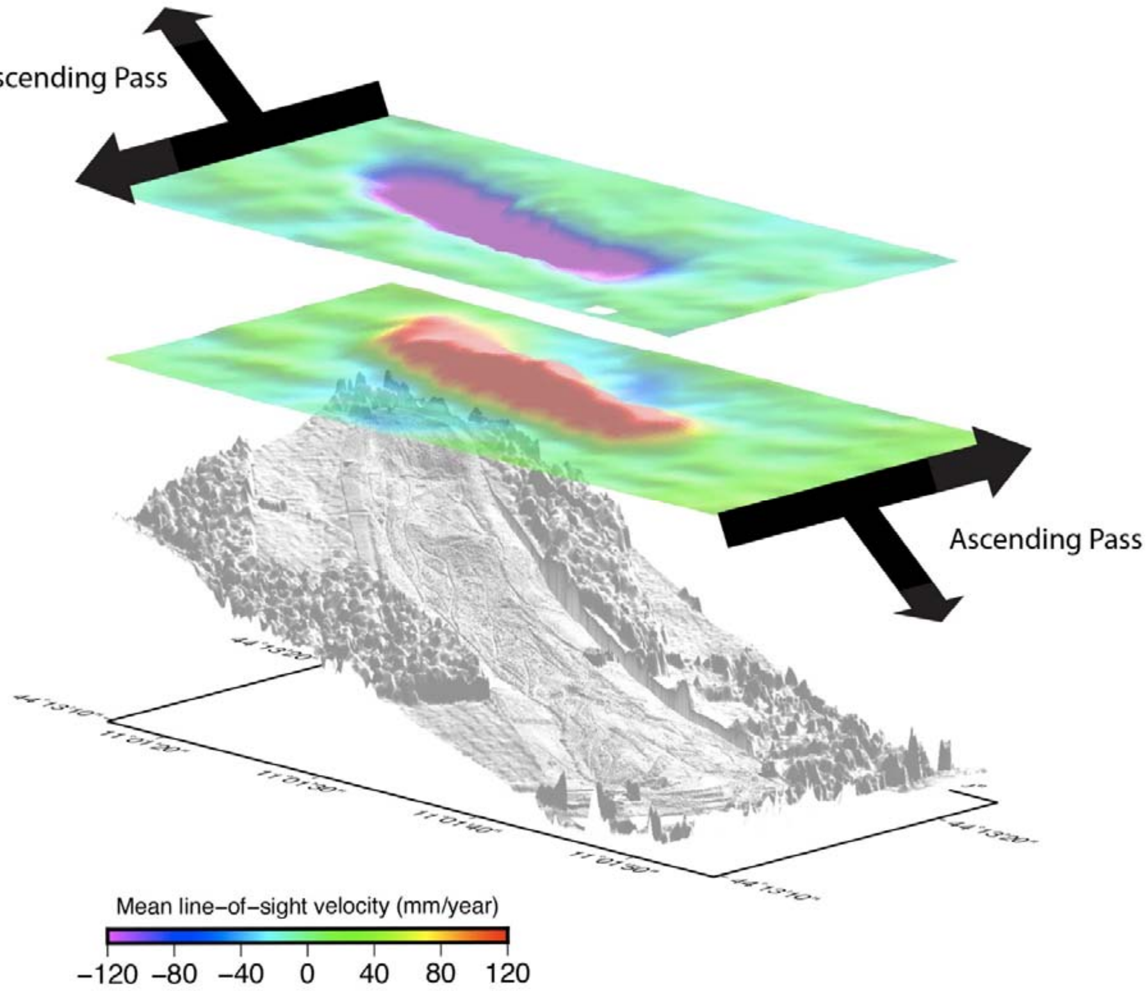
***Conclusions***

Observed landslide behavior

Limits and potential of standar InSAR

# Rationale

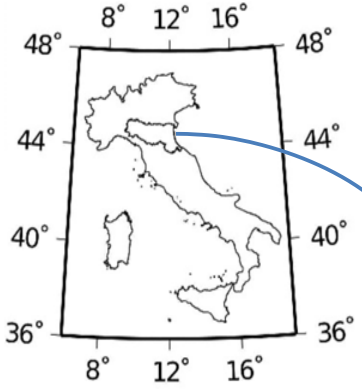
**Standard two-pass interferometry** is frequently used for the assessment of coseismic deformation and motion of glaciers, but few applications exist in literature that use it successfully to study landslide kinematics (e.g. Handwerger, 2015; Tong and Schmidt, 2016).




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

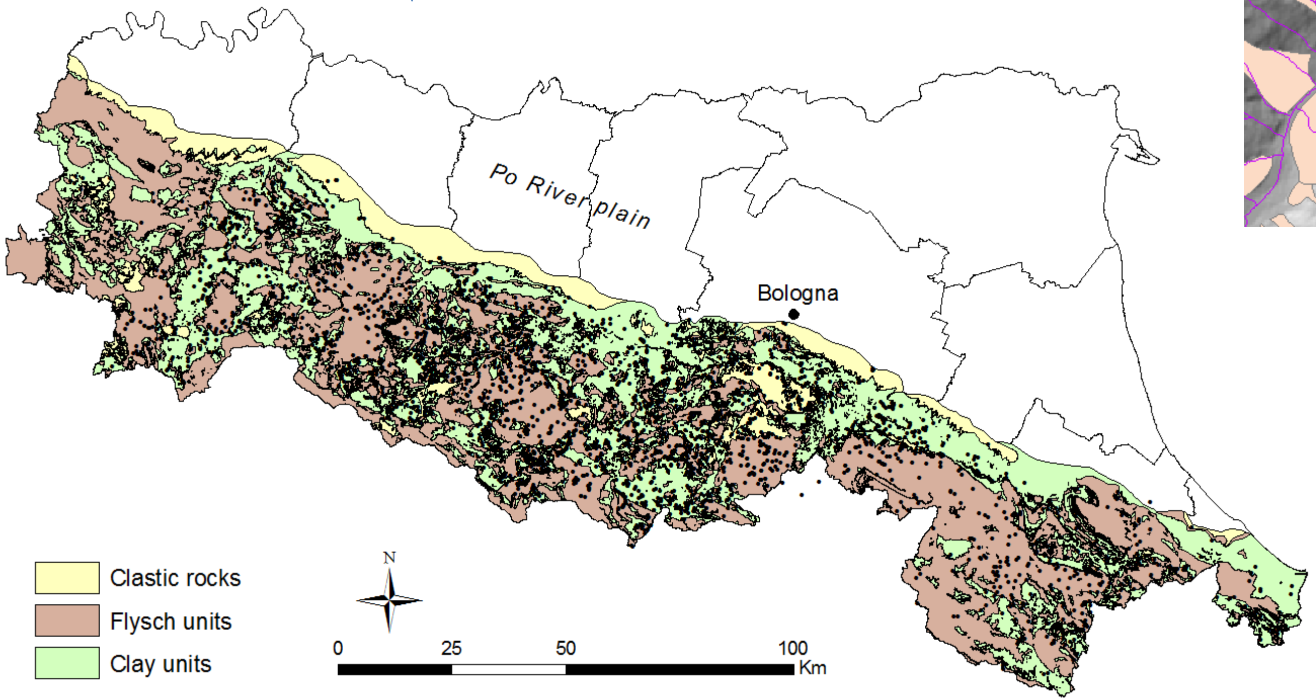
In the study area, most active landslide are often characterized by the scarcity of stable scatterers (e.g., houses, rock outcrops) and multitemporal InSAR tipically captures sparse pointwise deformation signals in these areas. Two pass interferometry can potentially produce a more complete picture of the deforming feature.

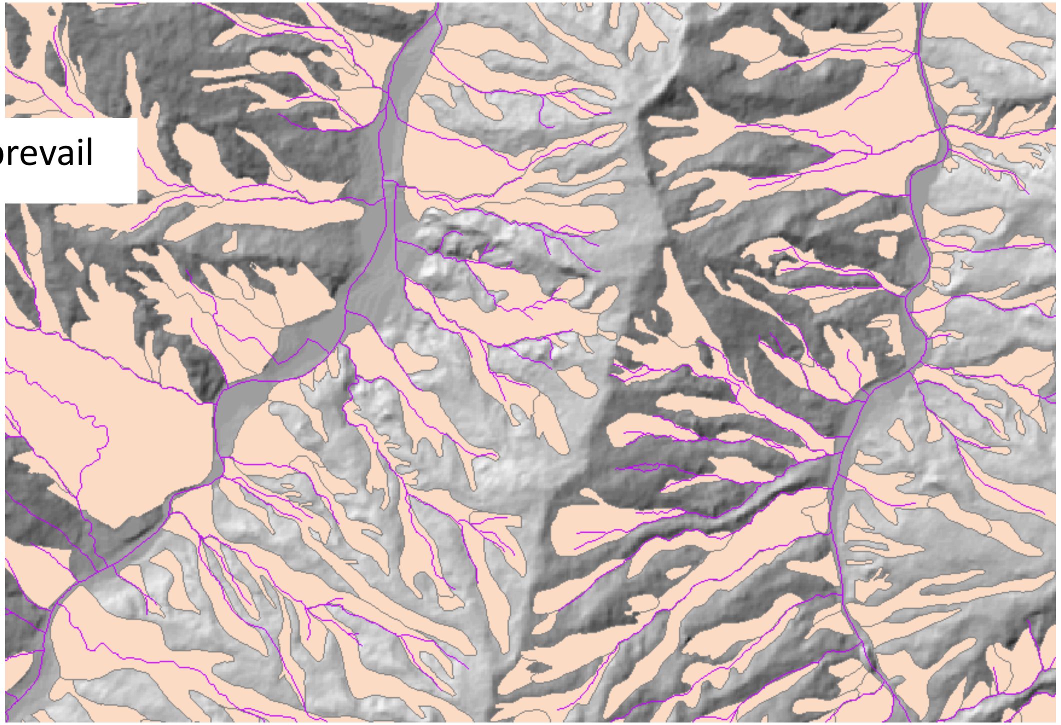
# Landsliding in the Northern Apennines




Young mountain chain where <u>weak lithologies</u> prevail

mountainous area: 11.500 km$^2$
more than **<u>70.000 mapped landslides</u>**,
about 50% are classified as active
landslide index in the clay units > 25%



More than 90% of registered landslides consist of **<u>reactivation of existing landslide deposits</u>**

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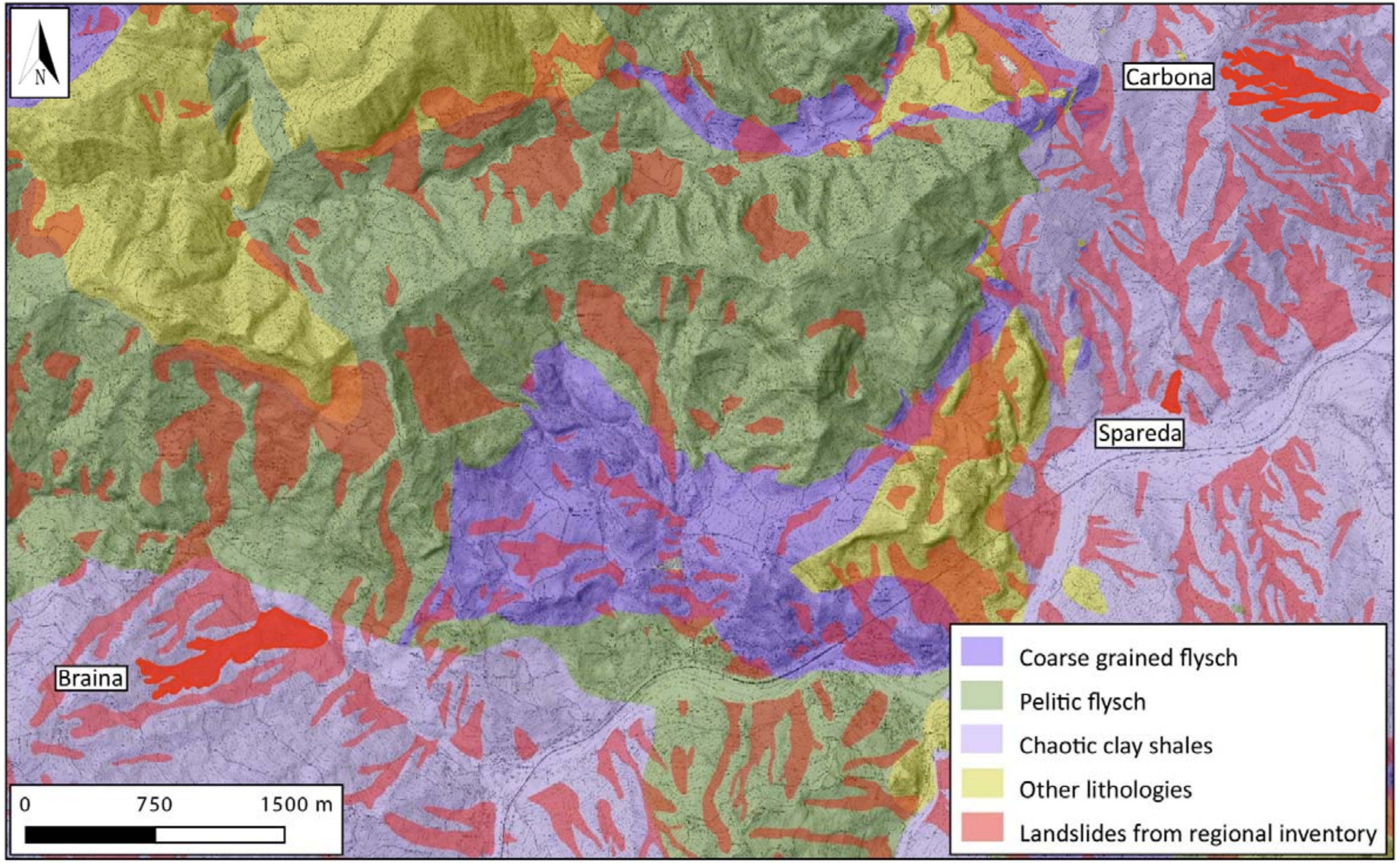
# Geology and landslides in the study area

The study area has an extension of 59 km$^2$.

The geology is mainly characterized by flysch and clays shales.

The regional inventory reports the presence of 186 landslides that are active or quiescent.




During November 2019,

heavy persistent rains

caused the reactivation of

3 landslides

Braina, Spareda e Carbona

# Methodology

We use **<u>conventional 2-pass SAR interferometry</u>** (standard InSAR) with data from the twin satellites Sentinel 1 to investigate pre- and post-failure deformations of landslides that were recently subject to reactivations.

SAR data were acquired with C-band antennas (5.6 cm wavelength) and a 6-day repeat interval.

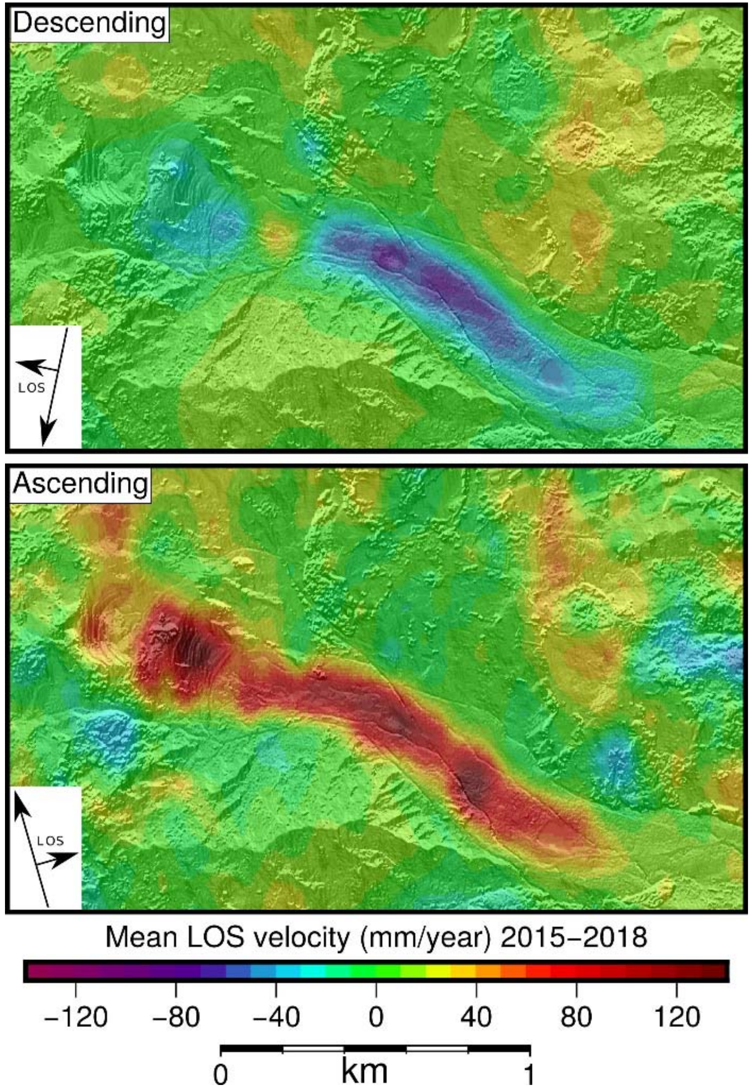
The images cover the period between 2015 and 2018 and our interferometric time spans range from 6 to 24 days.

<u>Part of the differential phase is caused by the deformation of the ground surface</u>, other parts of the interferometric phase are caused by common sources of noise: topography, atmosphere or orbital errors.

After the topographic and the atmospheric phase delays were estimated and removed, **<u>each interferogram was manually inspected</u>** to evaluate the residual noise vs. deformation signal.

Overall, more interferograms (2 datasets) for each analysis were processed for this study.

In particular, more than 1500 interferograms were used for the site-specific analysis and more than 1000 for the areal studies.



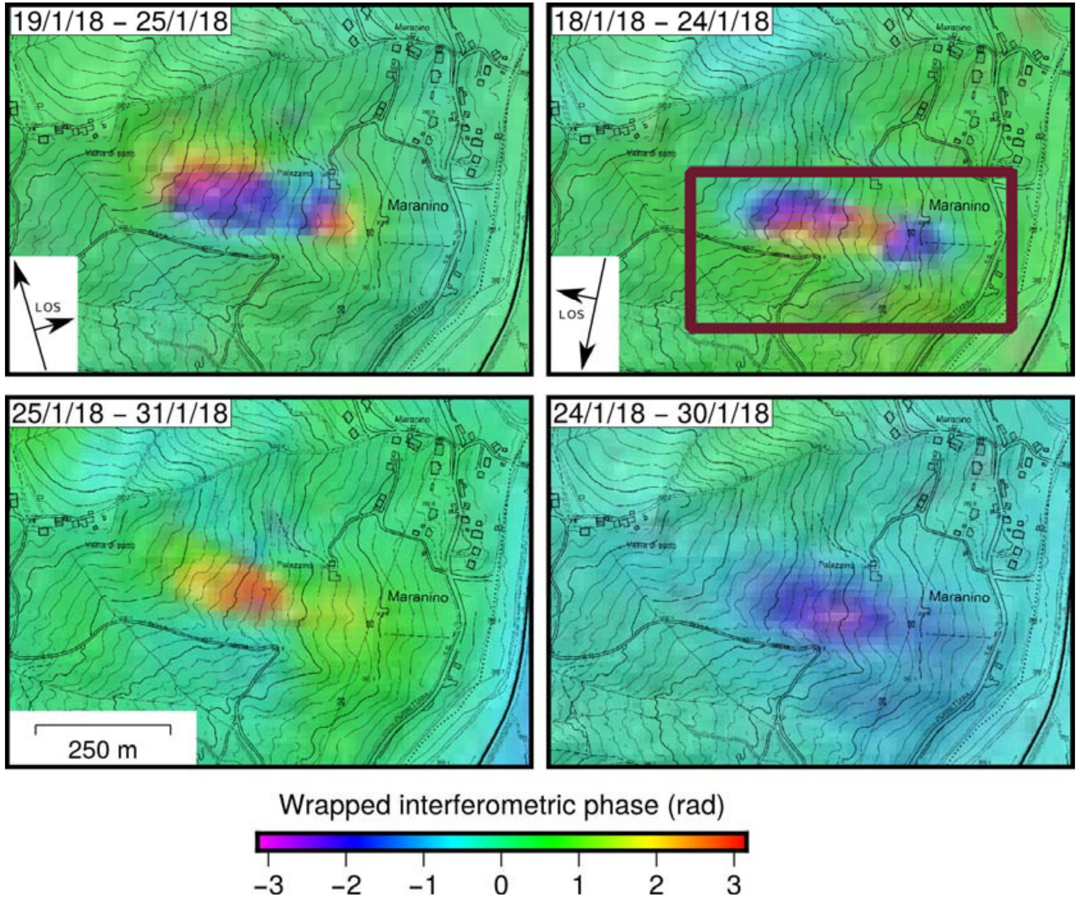
# Methodology

Selected interferograms have been unwrapped. When displacement rates were high, often phase jumps were not correctly resolved and we used a deformation modelling approach to solve these problems (e.g Handwerger et al., 2019).

The focused, local significance of the analysis allow to select a stable reference area that is used to further reduce atmospheric effects and residual noise.

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

Both the selection of processing parameters and the interferograms that are included in the analysis contain a subjective component.

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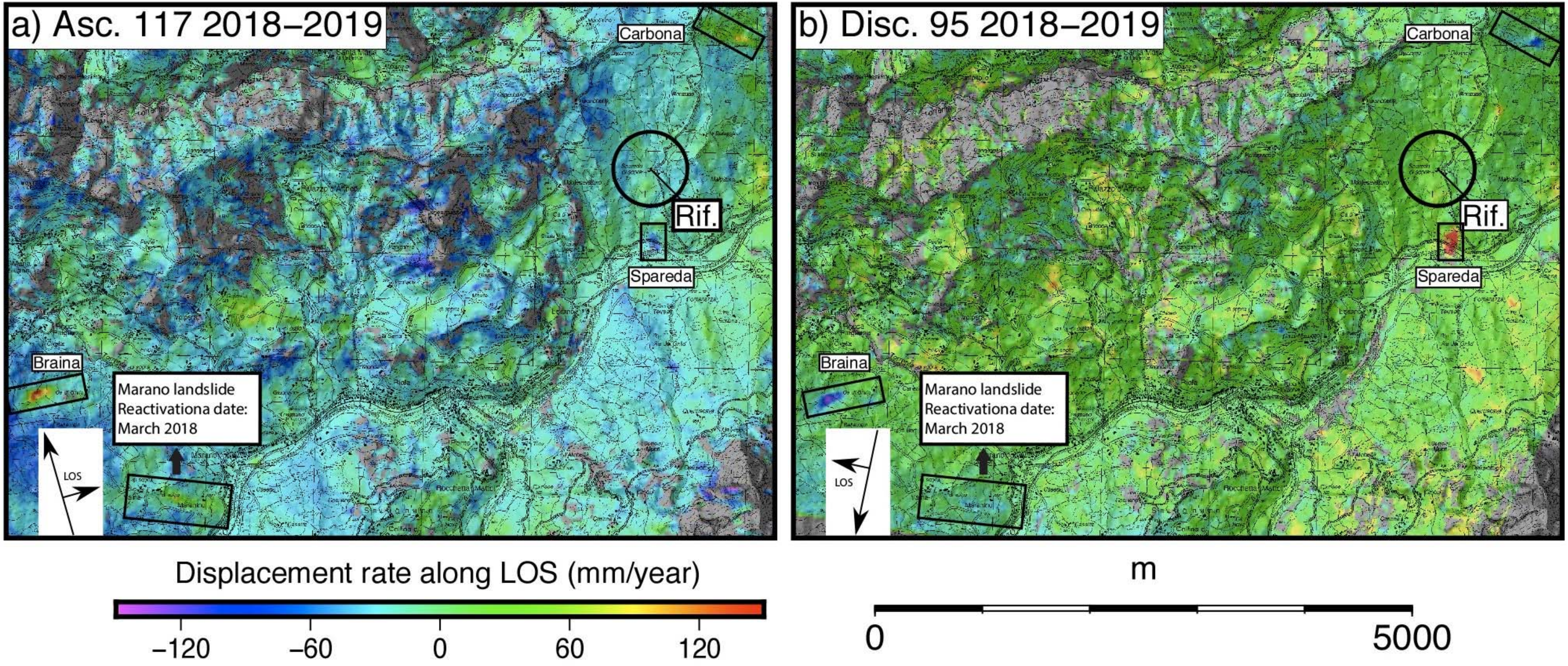
# InSAR areal analysis

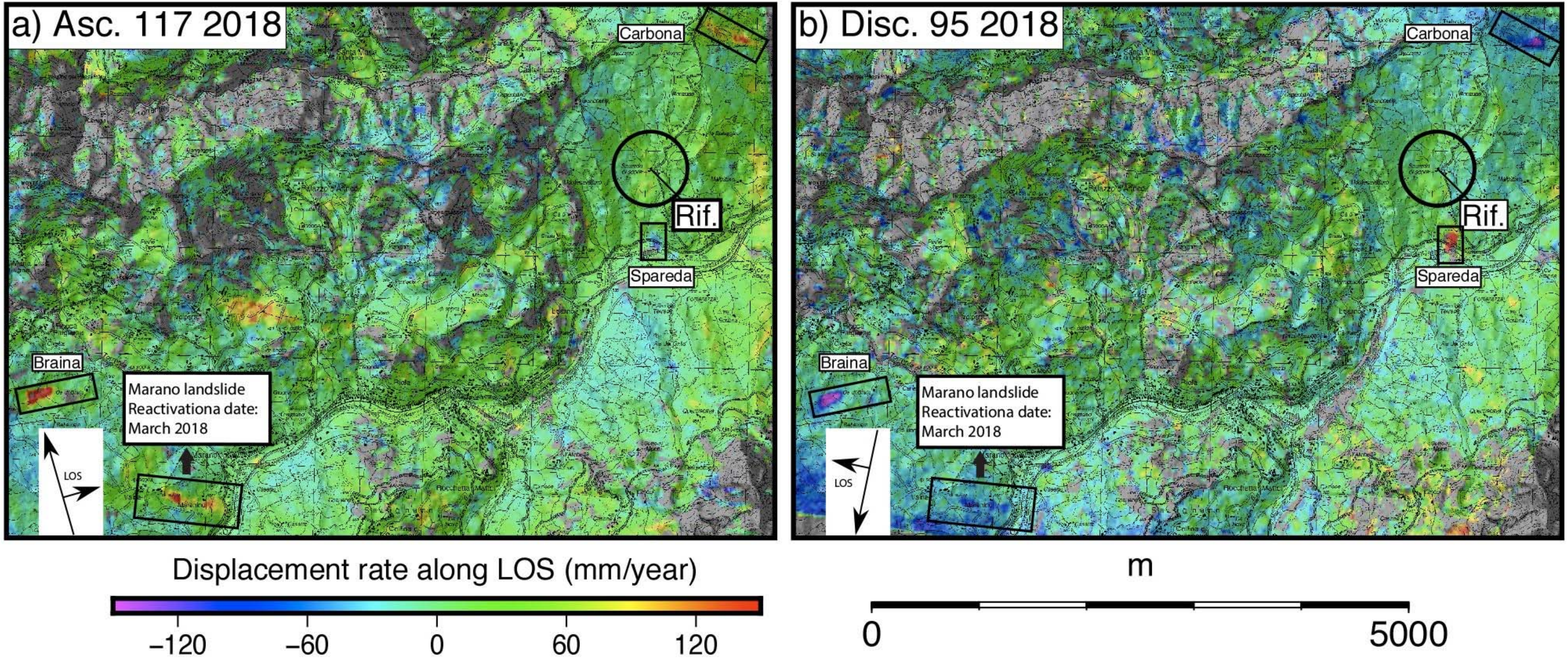
An areal analysis with this technique can be very useful to recognize landslides that have accelerated during the analysis period. In fact, in addition to the Marano landslide (activated in March 2018), the three landslides that are the subject of this work are clearly visible.




2018-19 Stack

# InSAR areal analysis

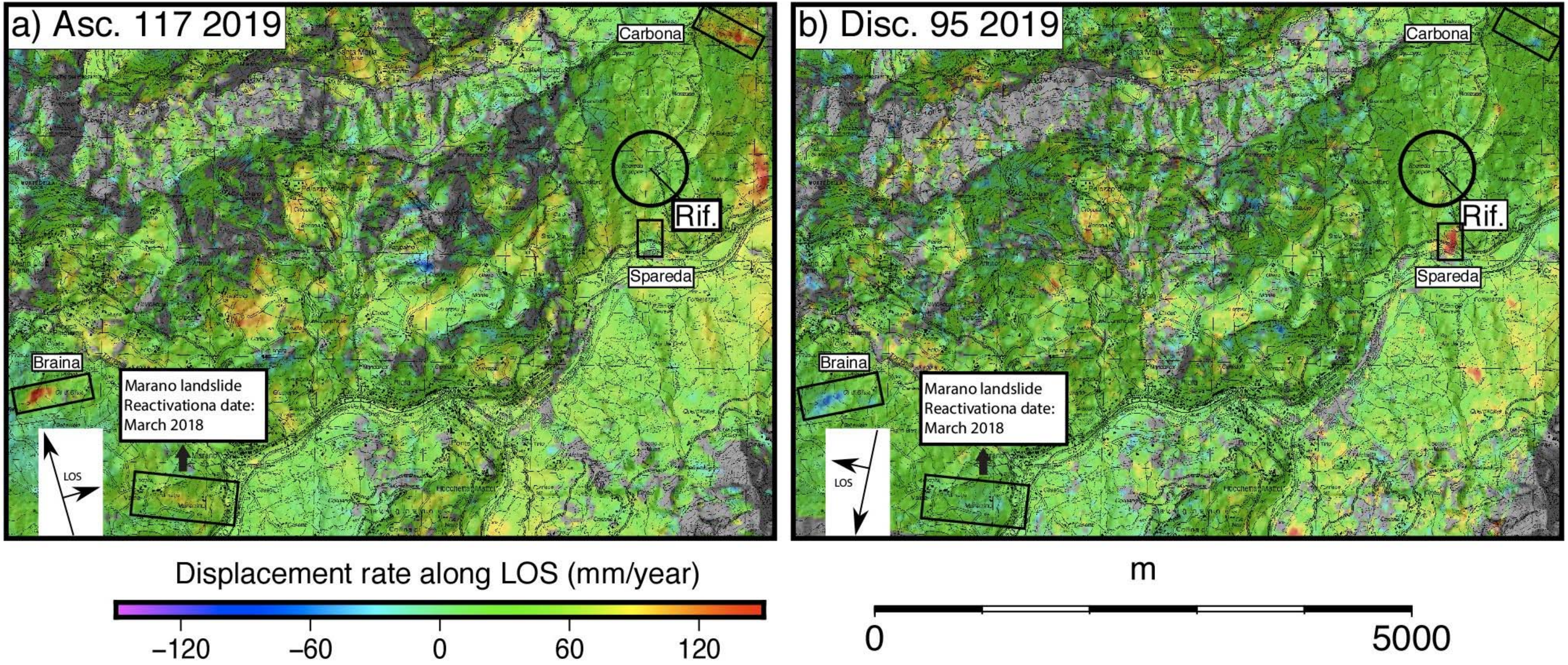
Displacement anomalies at Braina, Spareda and Carbona, are visible well in advance of their failures occurred in late 2019.




**2018 Stack**

# InSAR areal analysis

Despite the presence of tens of landslides in the study area, few displacement anomalies can be seen. They correspond to recently reactivated landslides (Marano) or landslides that experienced failure in late 2019.



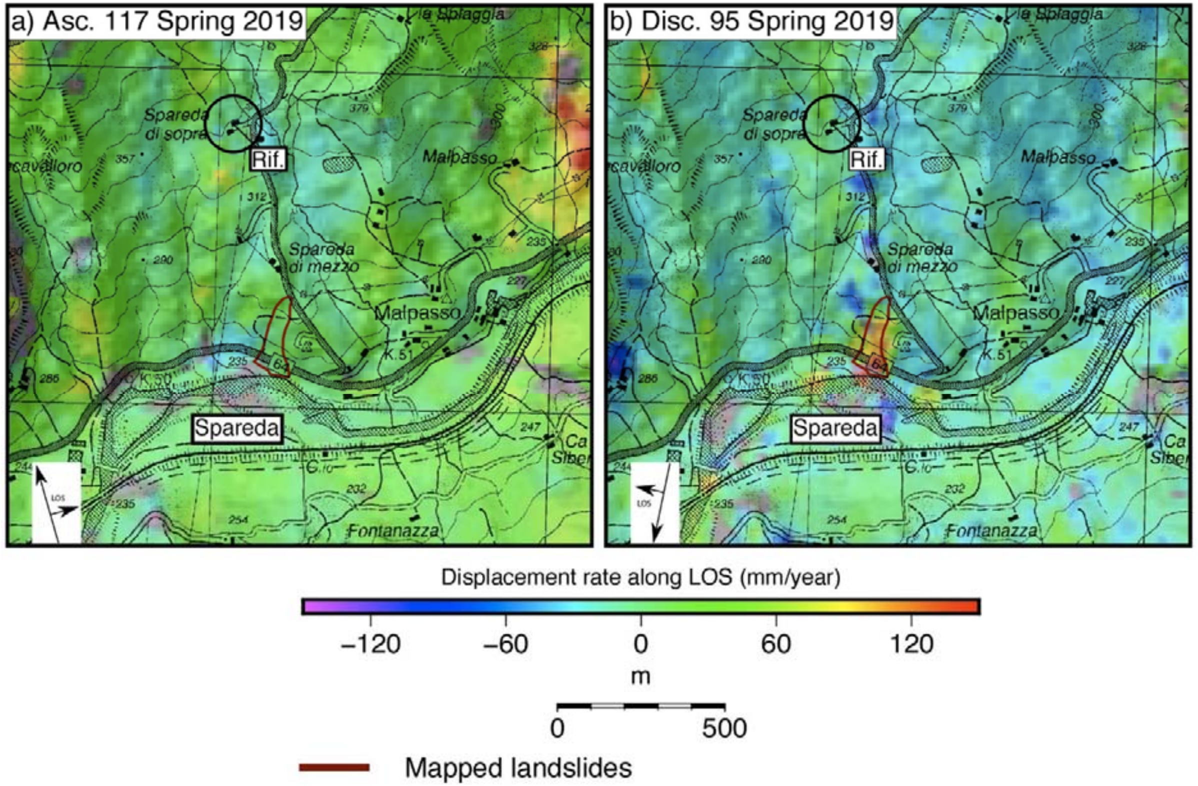

**2019 Stack**

# InSAR analysis: areal vs site-specific

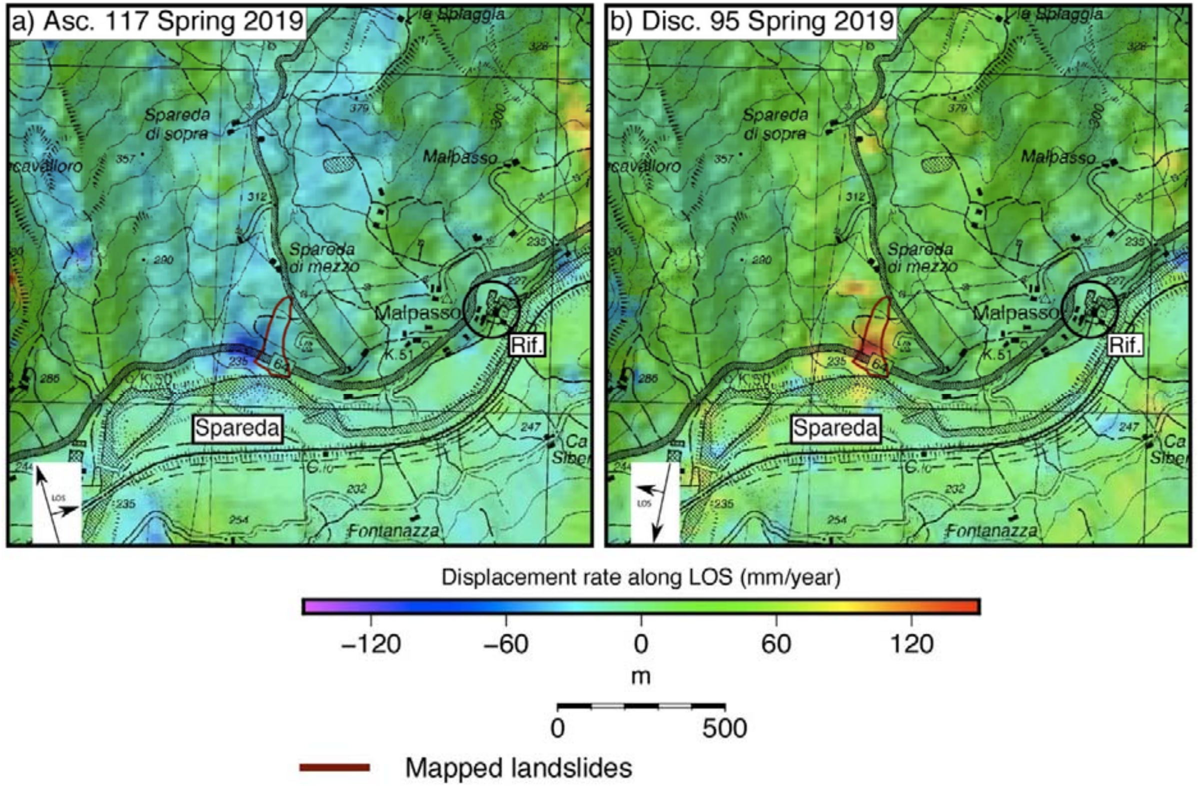
Site specific analysis improve the quality of the data. Factors such as different reference areas can influence the analysis. The site-specific analysis is more accurate, showing less noisy results on which the unwrapping process worked better.

The example of Spareda:

**Areal**




**Site-specific**

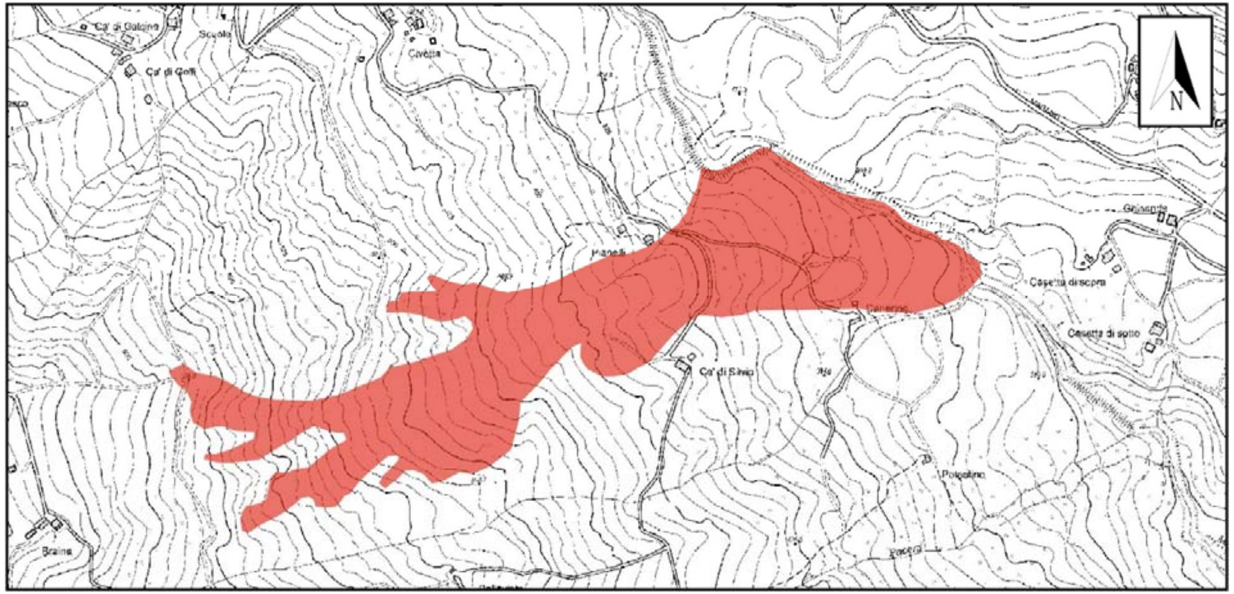


# Braina

Relief is made of Cretaceous Clay-shales
Dimensions: length 1250 m, width 100-450 m
Average slope: 12.6°

**<u>last known reactivation</u>**:

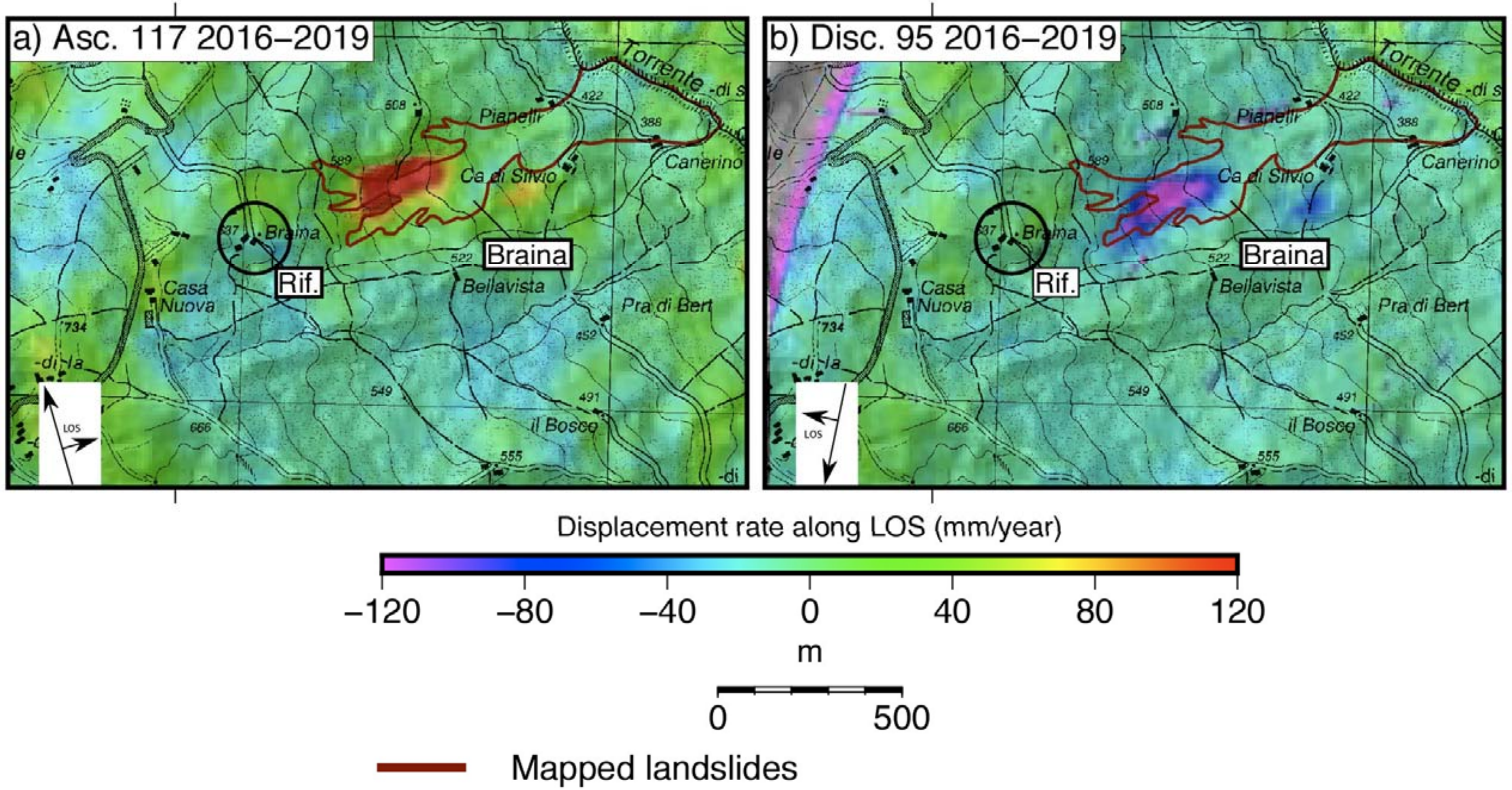
15-21 november 2019

# Braina

Stack of all manually-selected interferograms (January 2016 to December 2019) highlights the area subject to deformation.

Very similar spatial pattern are obtained from 2 different datasets.




Braina earthflow reactivated catastrophically during november 2019.

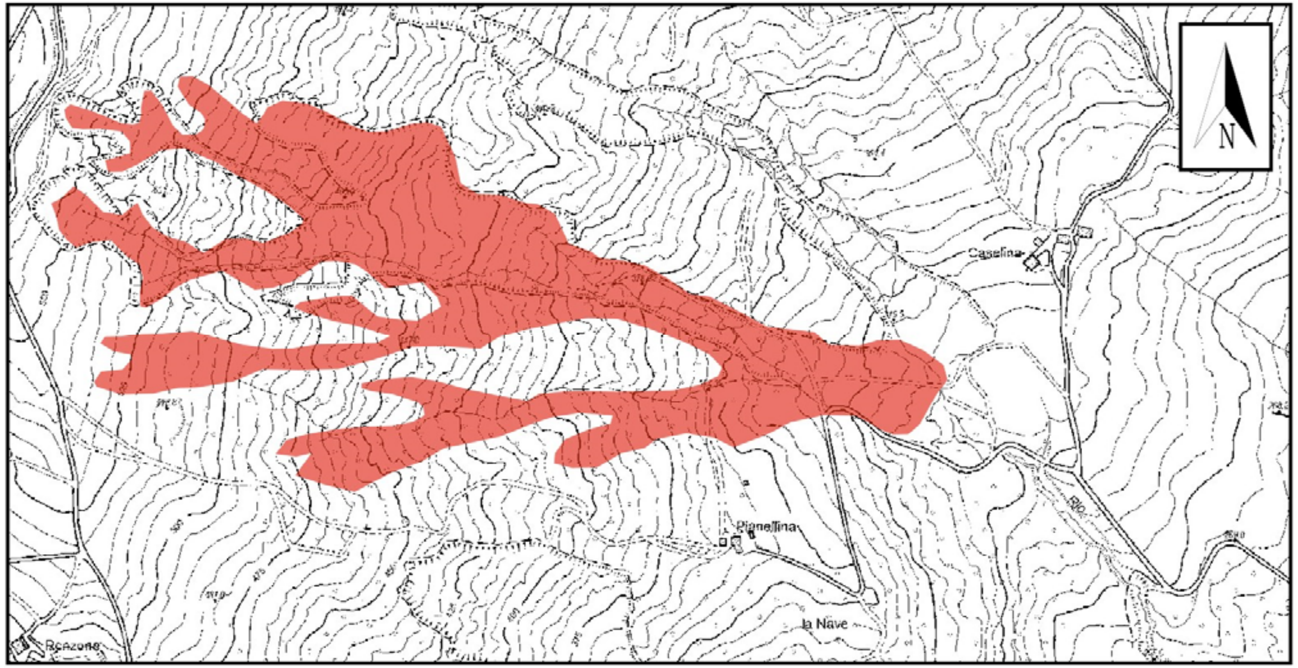
Standard InSAR reveals that **<u>the lanslide has been moving for at least two years before the catastrophic failure.</u>**

# Carbona

Relief is made of Cretaceous Clay-shales
Dimensions: length 1300 m, width 50-150 m
Average slope: 16.5°

**<u>last known reactivation</u>**:

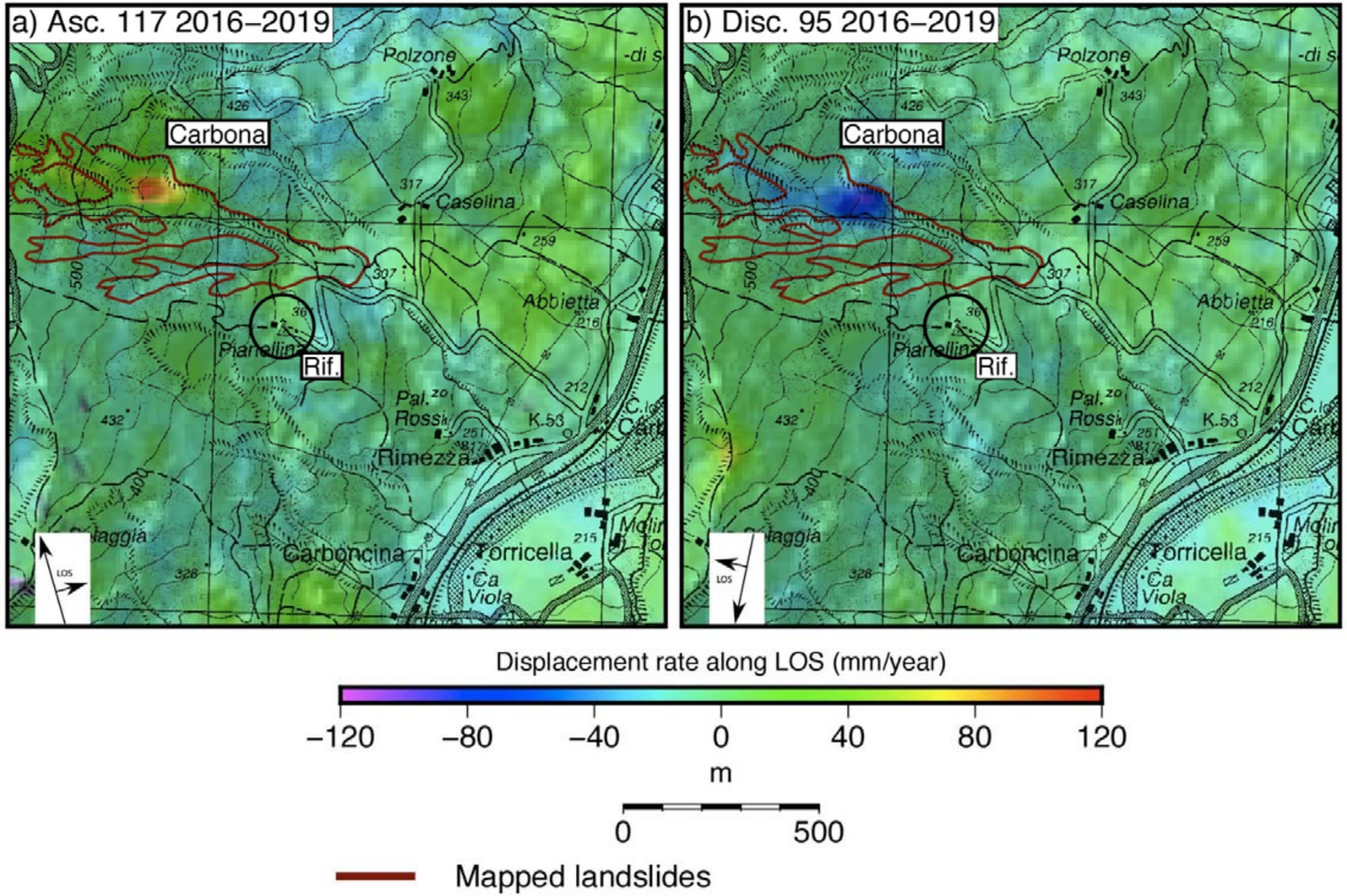
December 2019

# Carbona

Stack of all manually-selected interferograms (January 2016 to December 2019) highlights the area subject to deformation.

Very similar spatial pattern are obtained from 2 different datasets.




Carbona landslide reactivated catastrophically during december 2019.

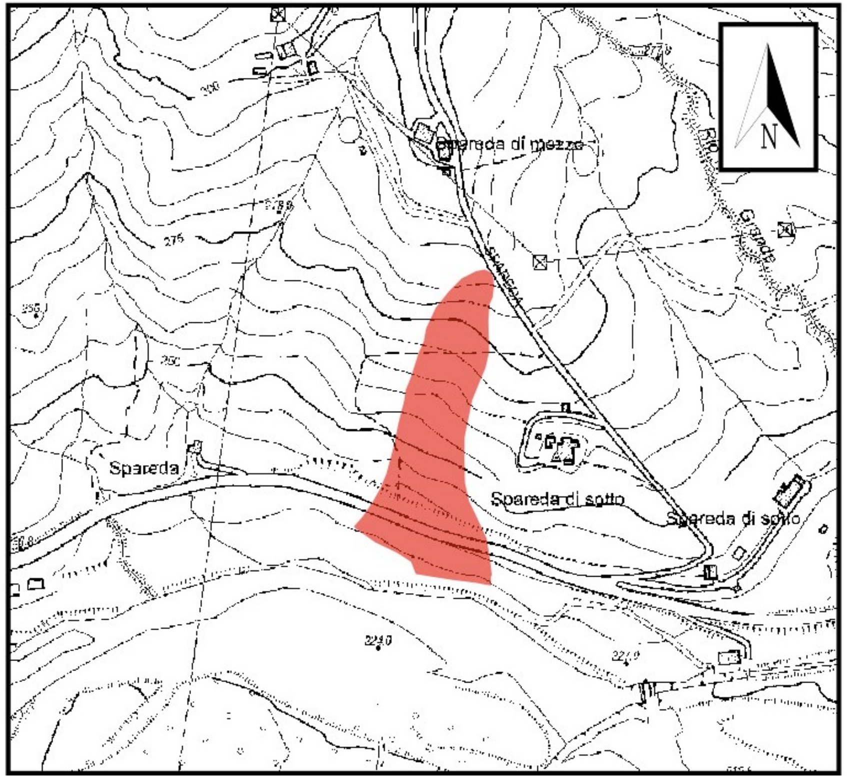
Standard InSAR reveals that **<u>the lanslide has been moving for at least two years before the catastrophic failure.</u>**

# Spareda

Relief is made of Cretaceous Clay-shales
Dimensions: length 240 m, width 50-130 m
Average slope: 15.7°

**<u>last known reactivation</u>**:

1-6 december 2019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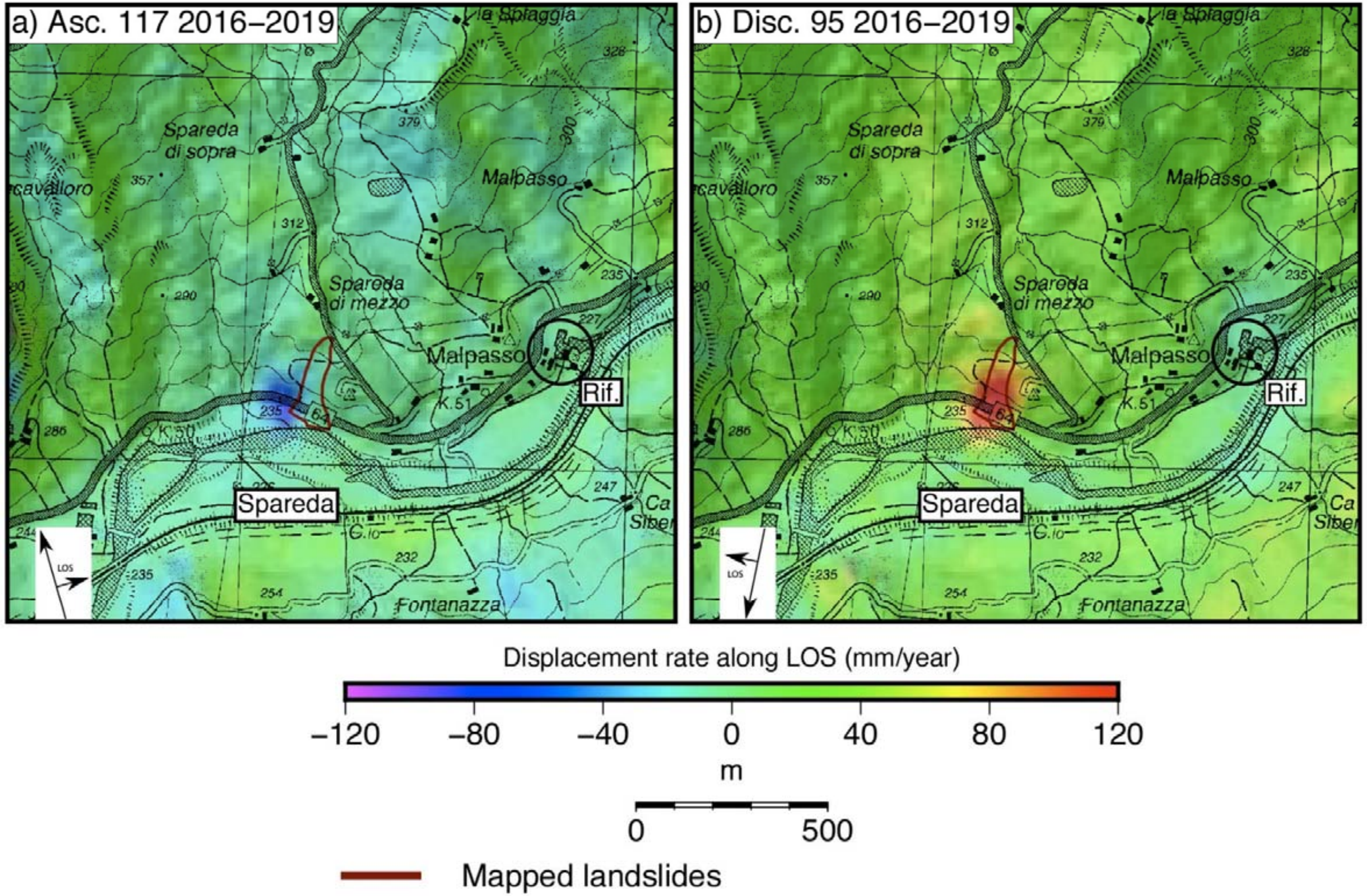
# Spareda

Stack of all manually-selected interferograms (January 2016 to December 2019) highlights the area subject to deformation.

Very similar spatial pattern are obtained from 2 different datasets.

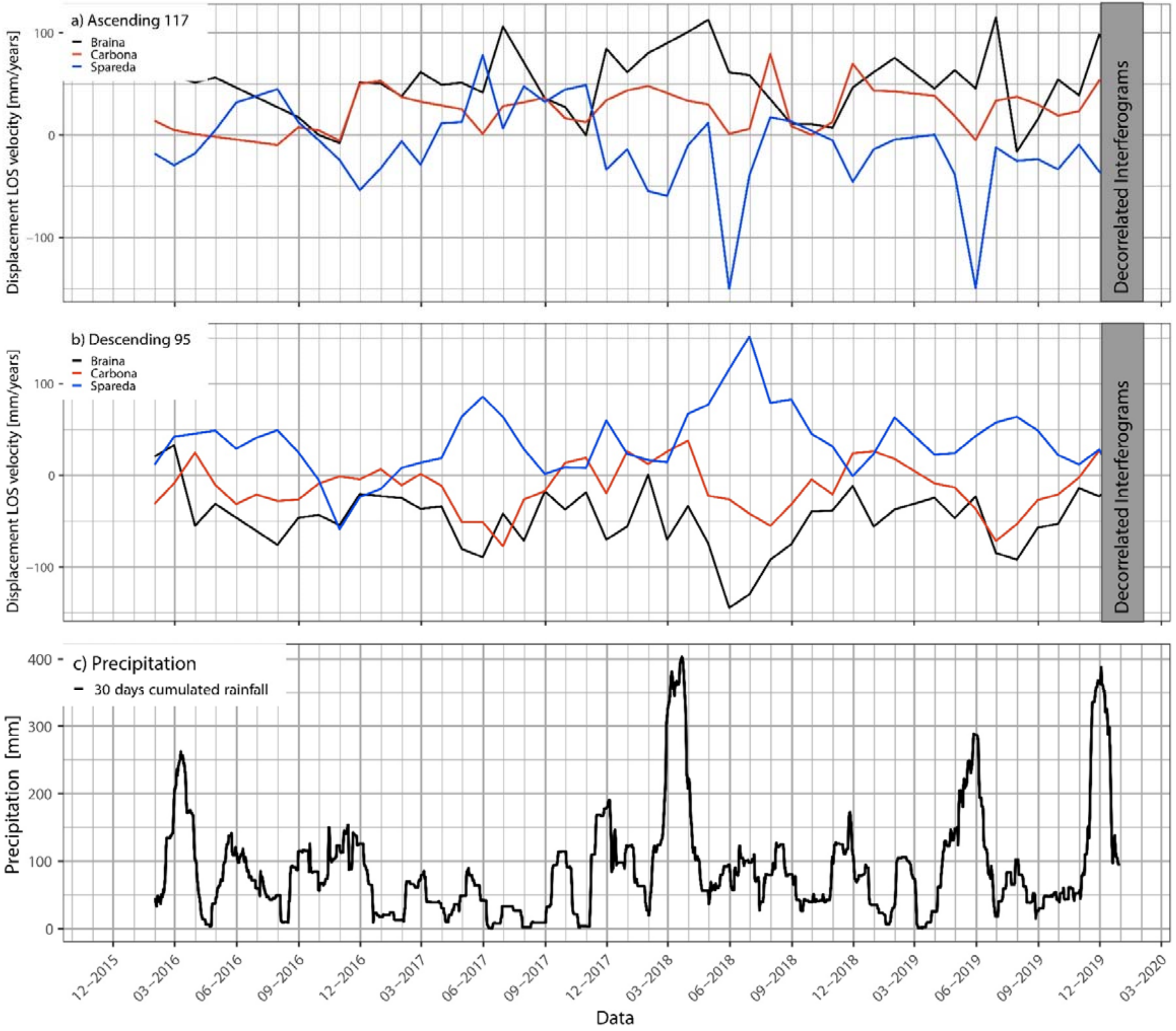



Spareda landslide reactivated catastrophically during december 2019.

Standard InSAR reveals that **<u>the lanslide has been moving for at least two years before the catastrophic failure.</u>**

# Braina – Carbona - Spareda

Velocities are used to derive time series and explore the temporal trend of deformation.




Major acceleration episodes are synchronous for the three landslides and related to wettest periods (April 2018, May 2019).

The displacement LOS velocity is the mean velocity of all pixels into the landslide polygons, derived from monthly stacks.

# Conclusions

### *Standard InSAR*

Standard InSAR can effectively detect surface displacements of landslides and its spatial pattern prior to their reactivation. ➔ Potential implication hazard recognition.

Inherent uncertainties in velocity measurements (residual noise, high displacement rates) remain but the evolution of the deformation with time is consistently observed. ➔ Potential implication for hazard forecasting.

### *Reactivation of Slow-moving landslides*

Catastrophic reactivation of slow-moving landslides is often preceded by detactable deformation.

The timing of failure is difficult to predict based on the observed displacement trend, however the landslides that reactivated during late 2019 showed evident velocity anomalies for the two preceding years.

The relationship between precipitation and landslide deformation is confirmed, our InSAR analysis show rainfall-driven displacement rates increase.

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