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Perspectives on the prediction of catastrophic slope failures from satellite InSAR

Federico Raspini, Tommaso Carlà, Emanuele Intrieri, Federica Bardi, Paolo Farina, Alessandro Ferretti, Davide Colombo, Fabrizio Novali, Nicola Casagli

Slope failure prediction – local scale

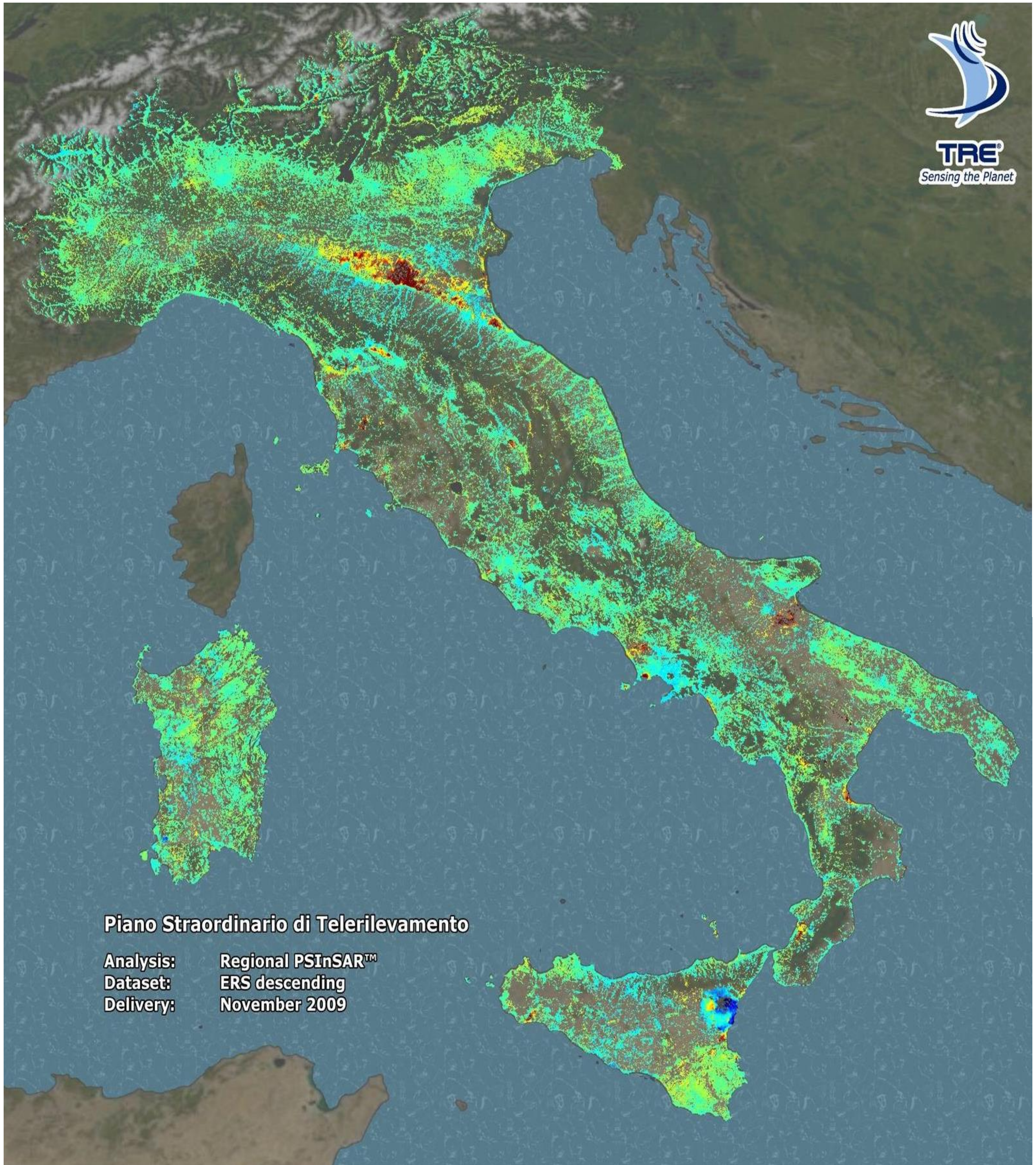

The "Sciara del Fuoco" at the Stromboli volcano

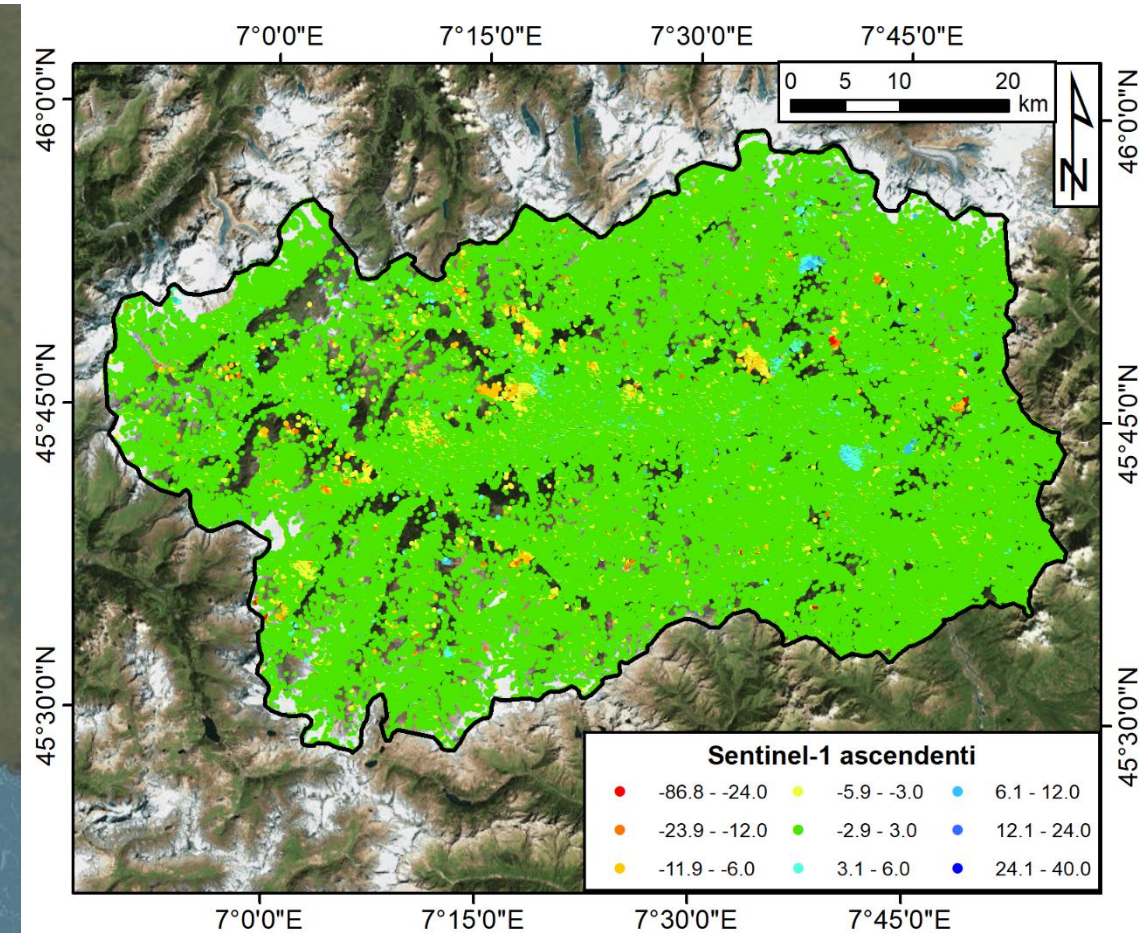

Tha Gallivaggio rockfall

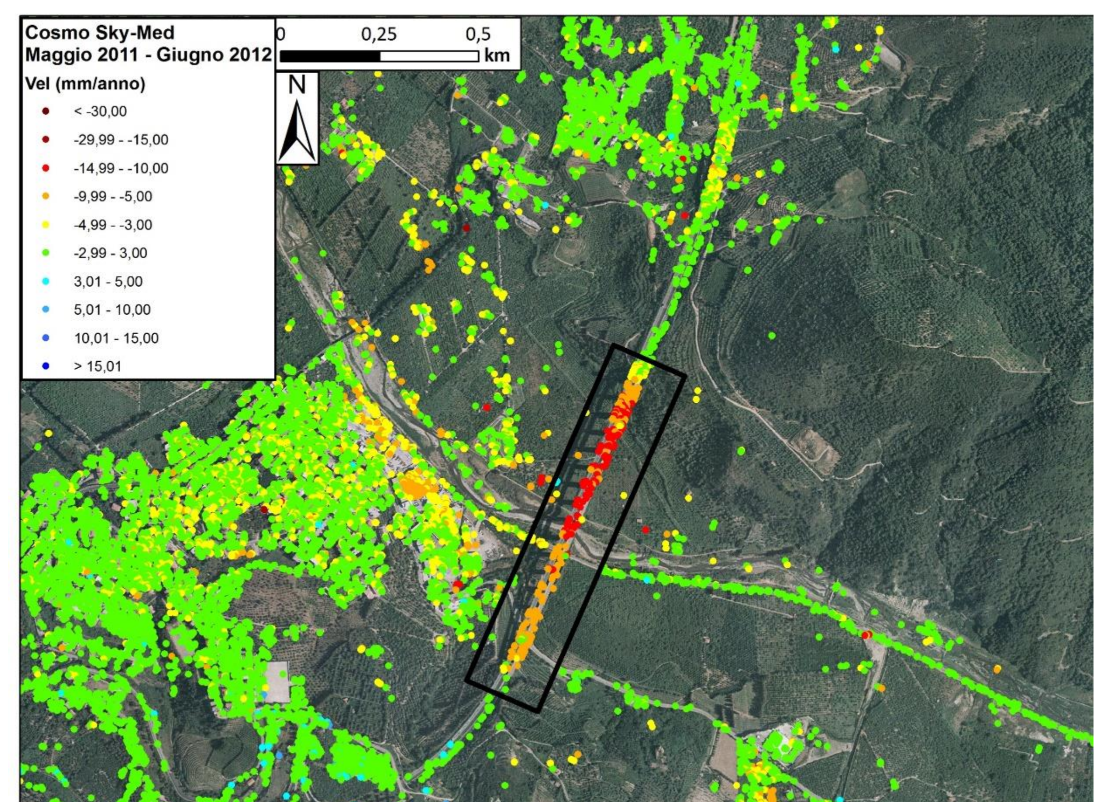

The Monte Beni landslide


Volterra city walls

Satellite InSAR – regional scale



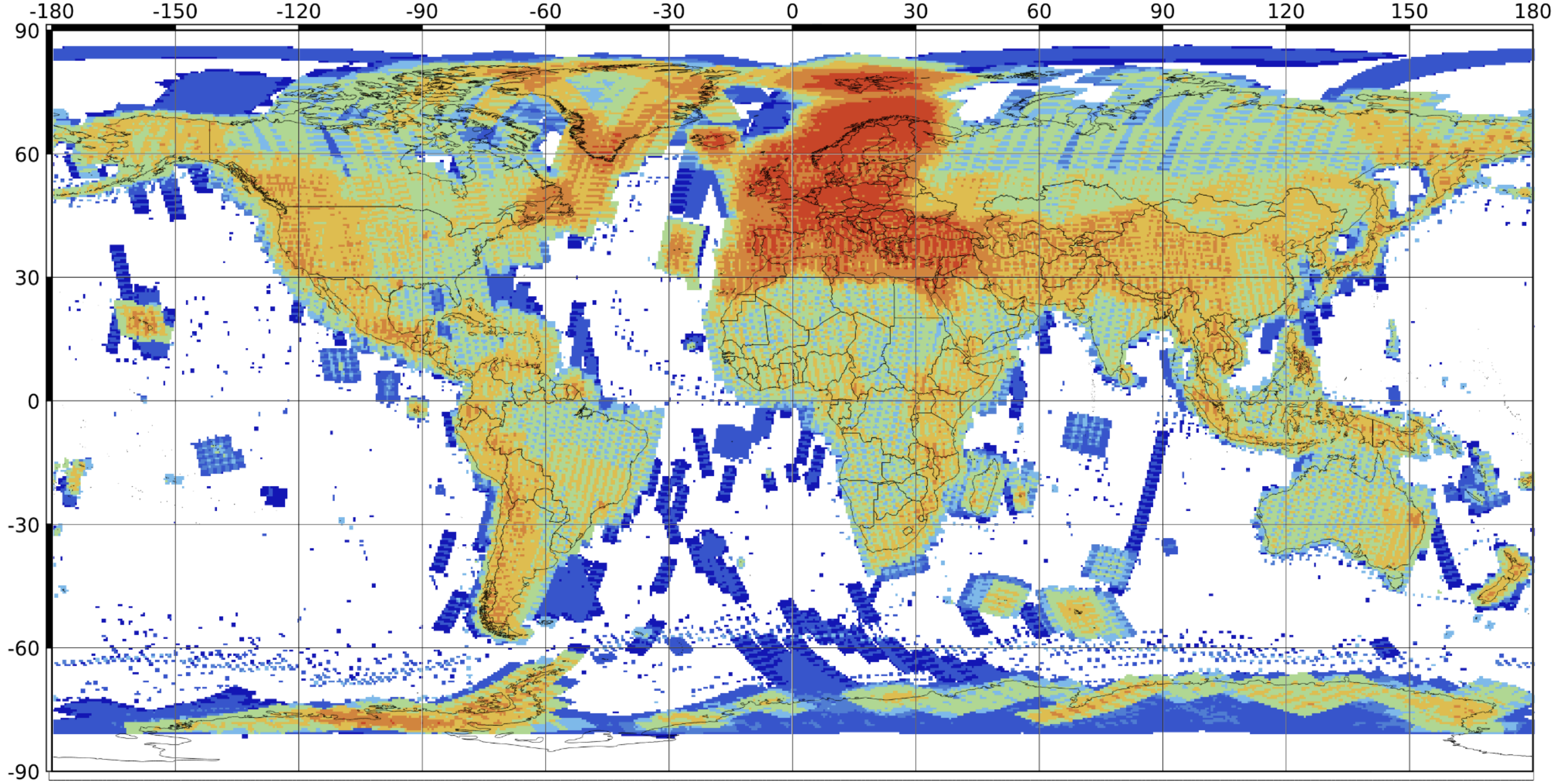


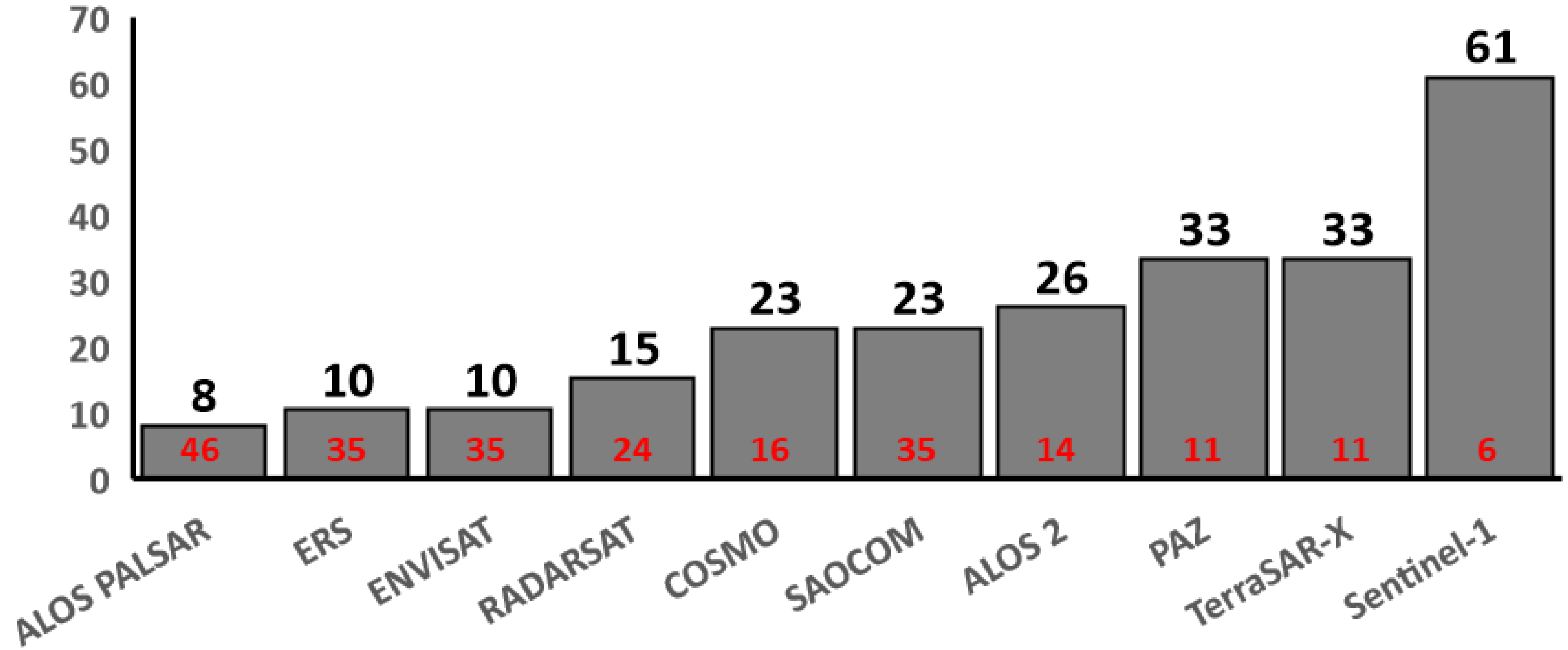


Sentinel-1

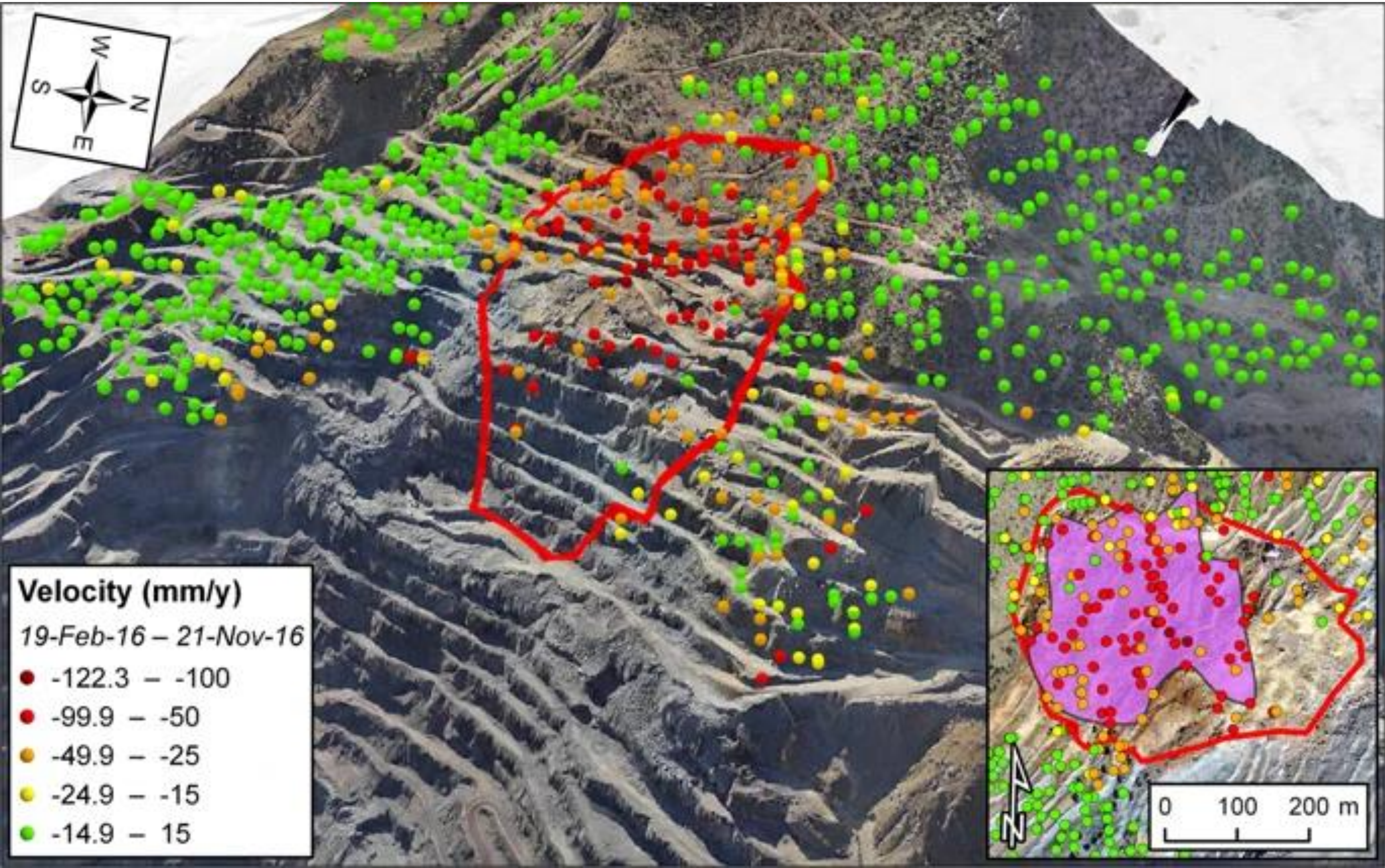
Revisiting time of 6 days

Sentinel-1: conflict-free operation mode

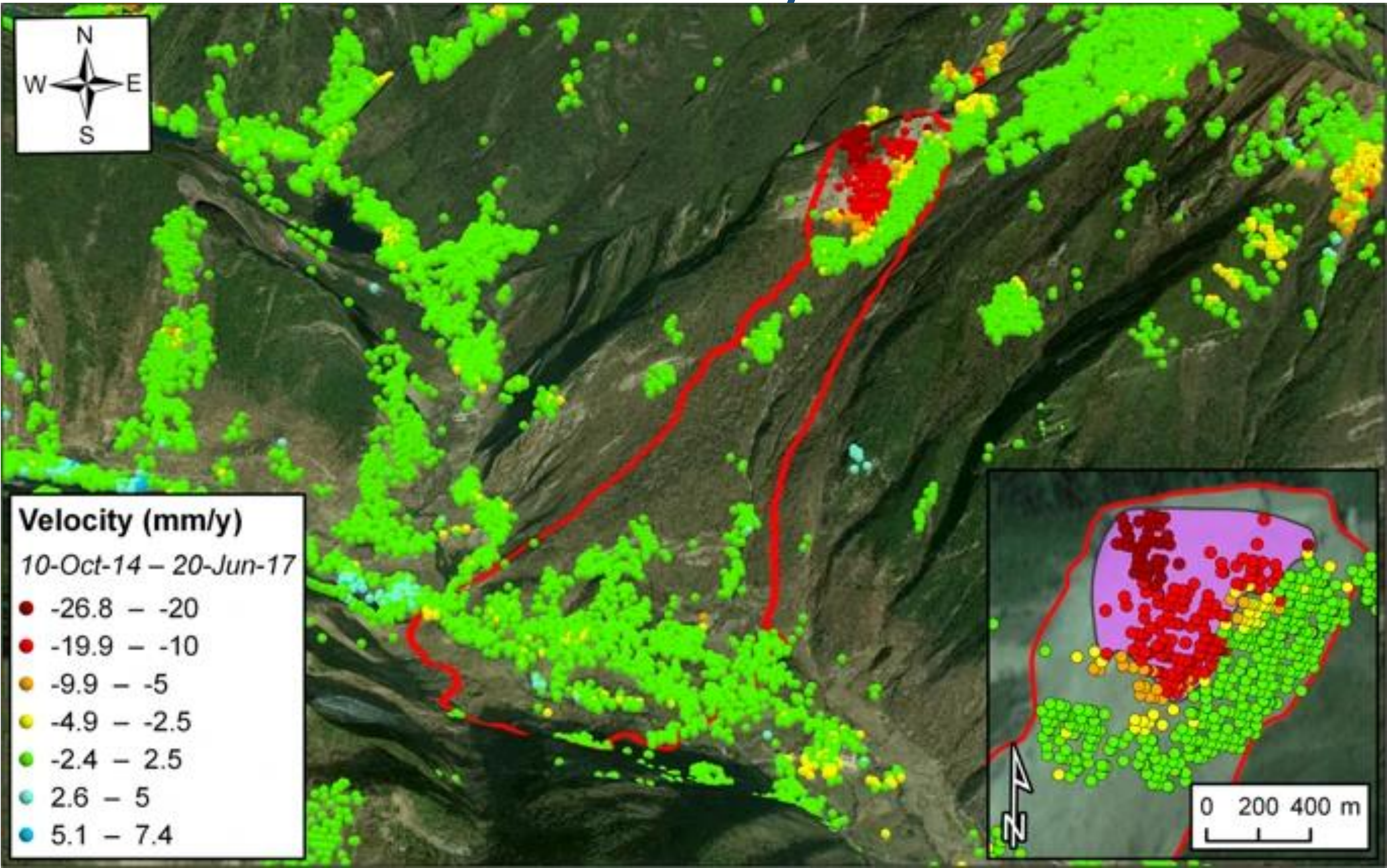




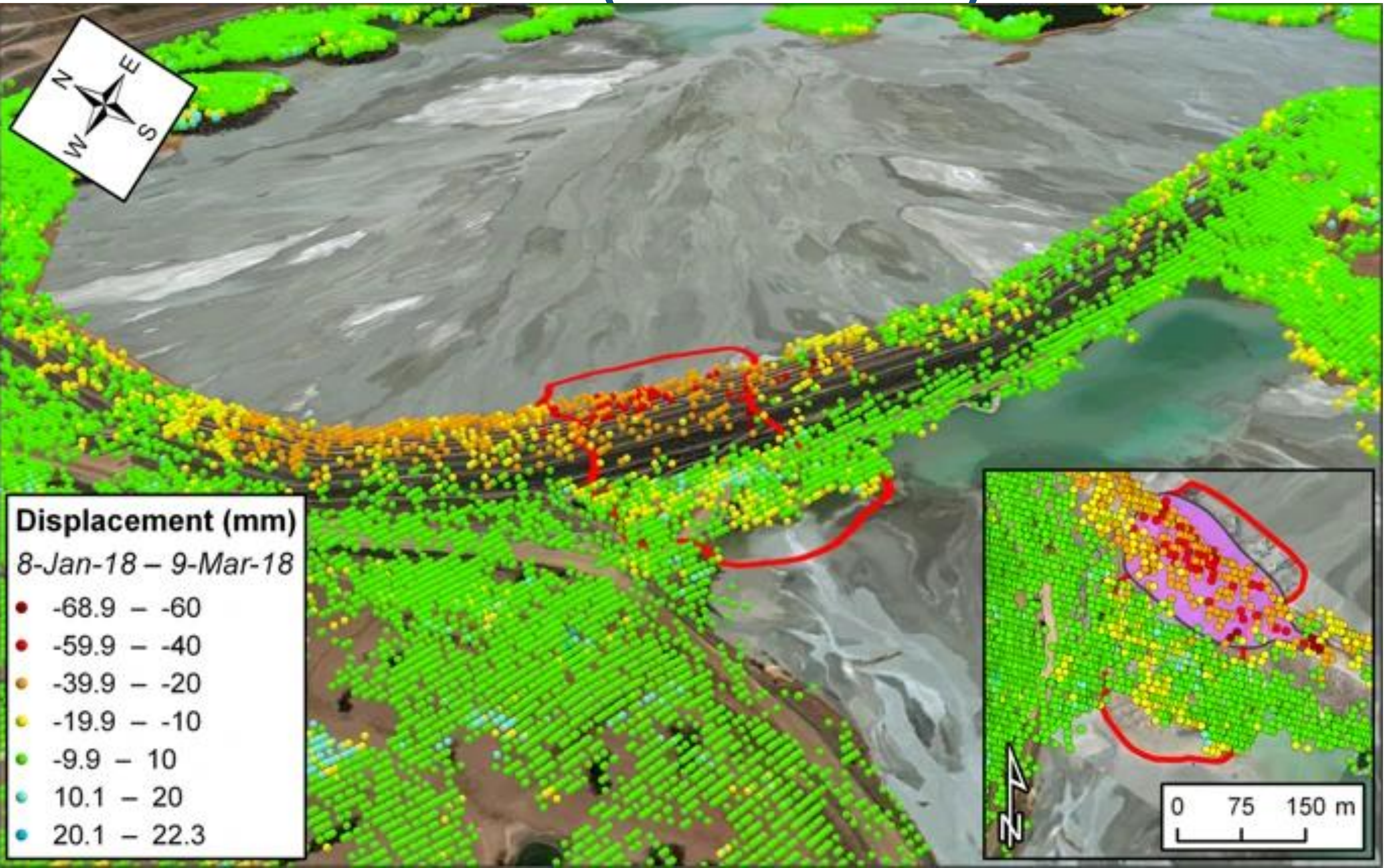
Open-pit mine slope instability



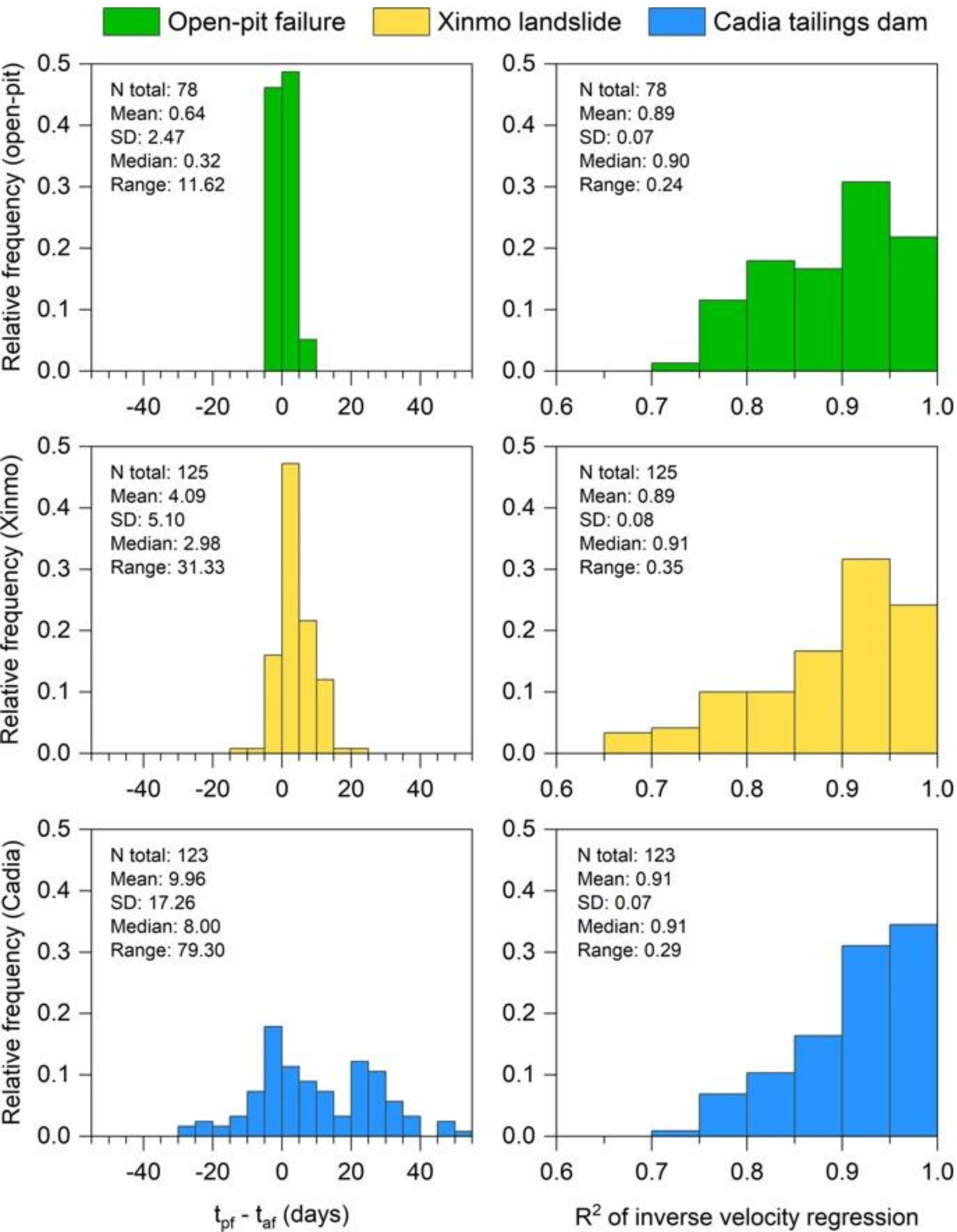
Time Xinmo landslide (Sichuan, China)



Failure of a tailings dam at Cadia gold mine (Australia)

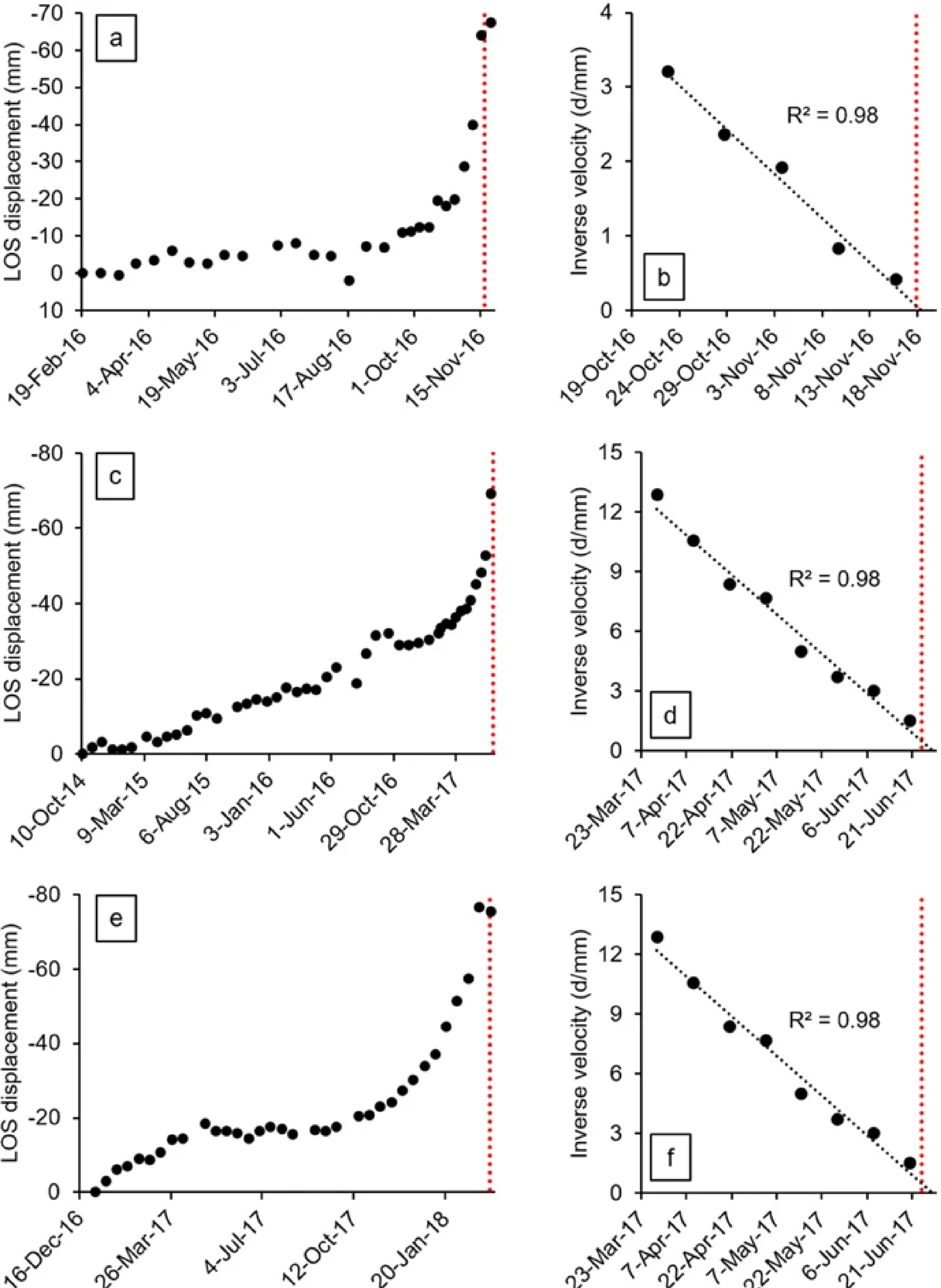


Predictive ability



The relative frequency distribution of the errors (*i.e.* $t_{pf}-t_{af}$, where t_{pf} is the predicted time of failure and t_{af} the actual time of failure) and of the R^2 values was also computed to provide a measure of the predictive ability that may be deduced from the three stacks of Sentinel-1 images.

Inverse velocity plot



Example of accelerating trend and resulting inverse velocity regression related to:

(a,b) the failure of the investigated open-pit mine slope;

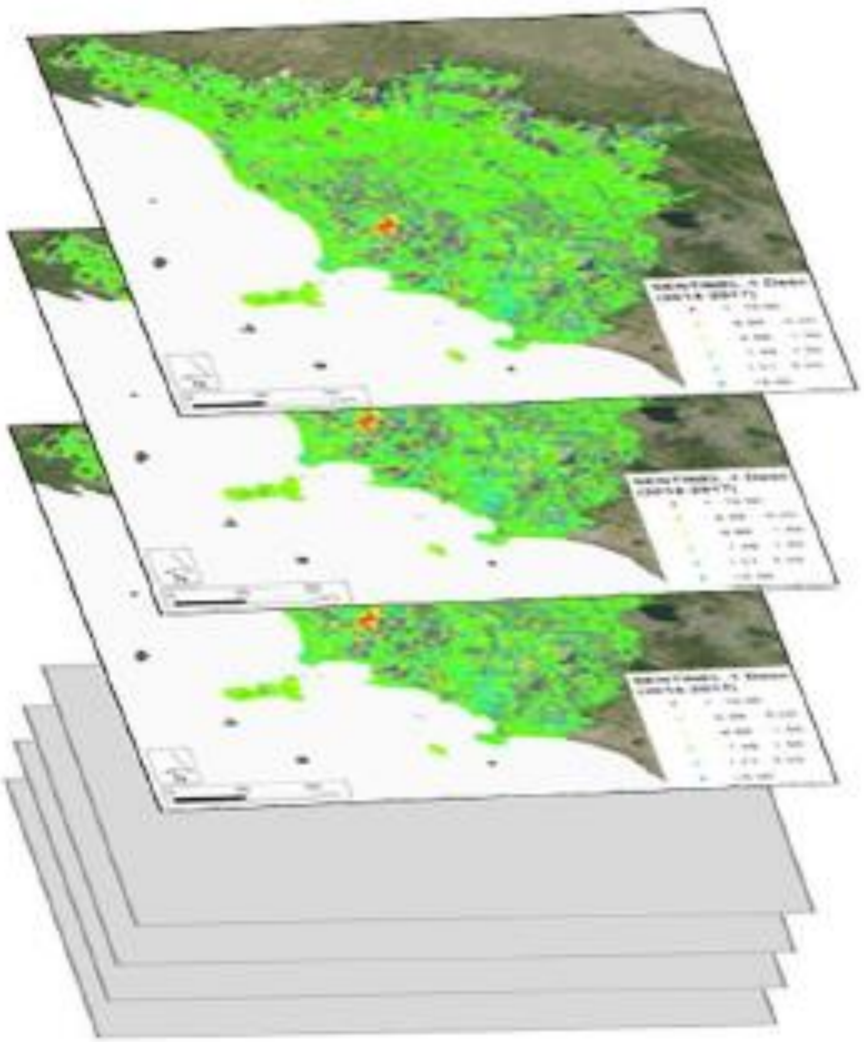
(c,d) the Xinmo landslide;

(e,f) the failure of the Cadia gold mine northern TSF.

The red dotted lines indicate the actual failure-time.

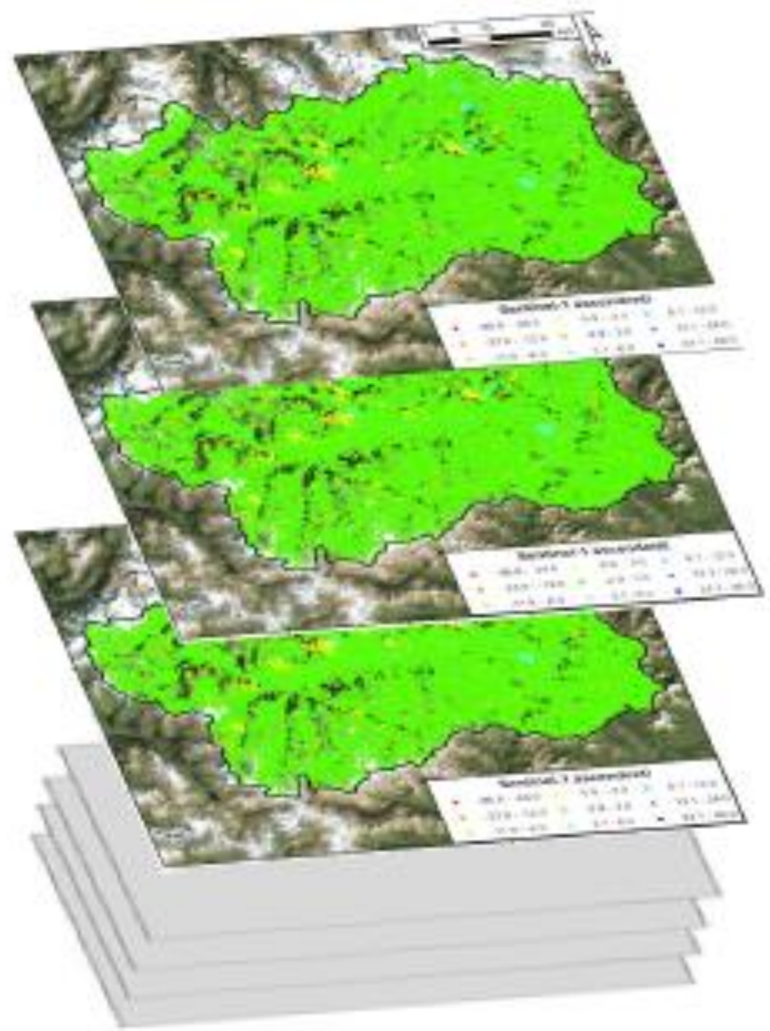
Continuous monitoring at regional scale

Tuscany region



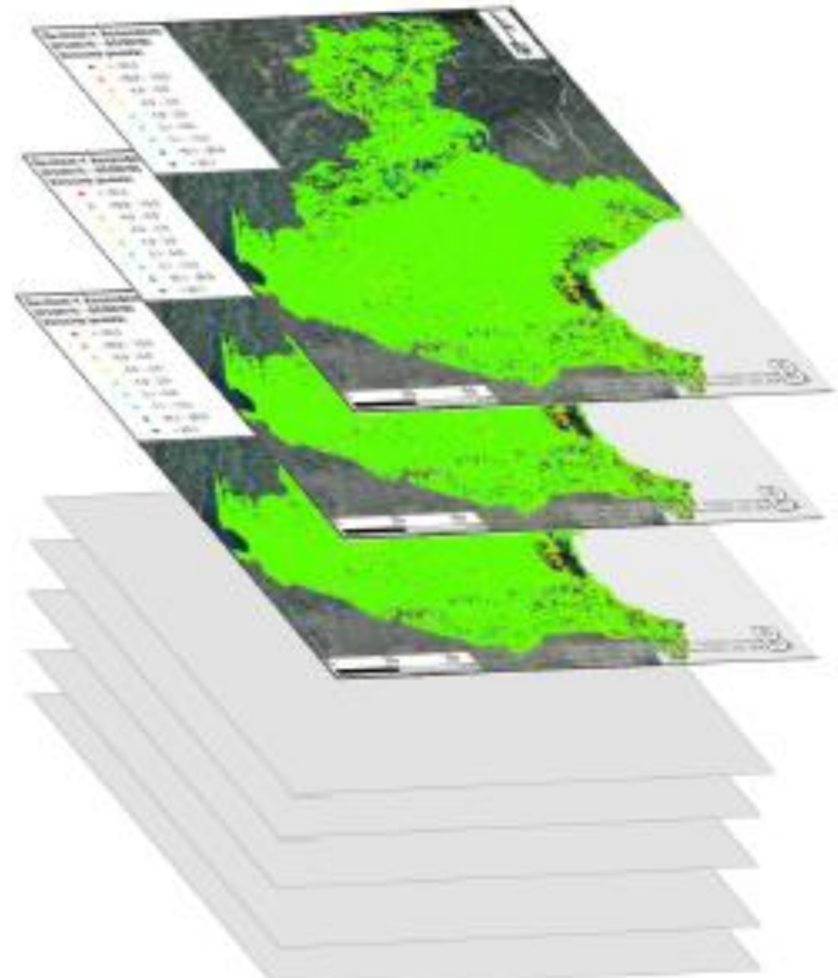
≈ 2.000.000 PSs

Valle d'Aosta region



≈ 700.000 PSs

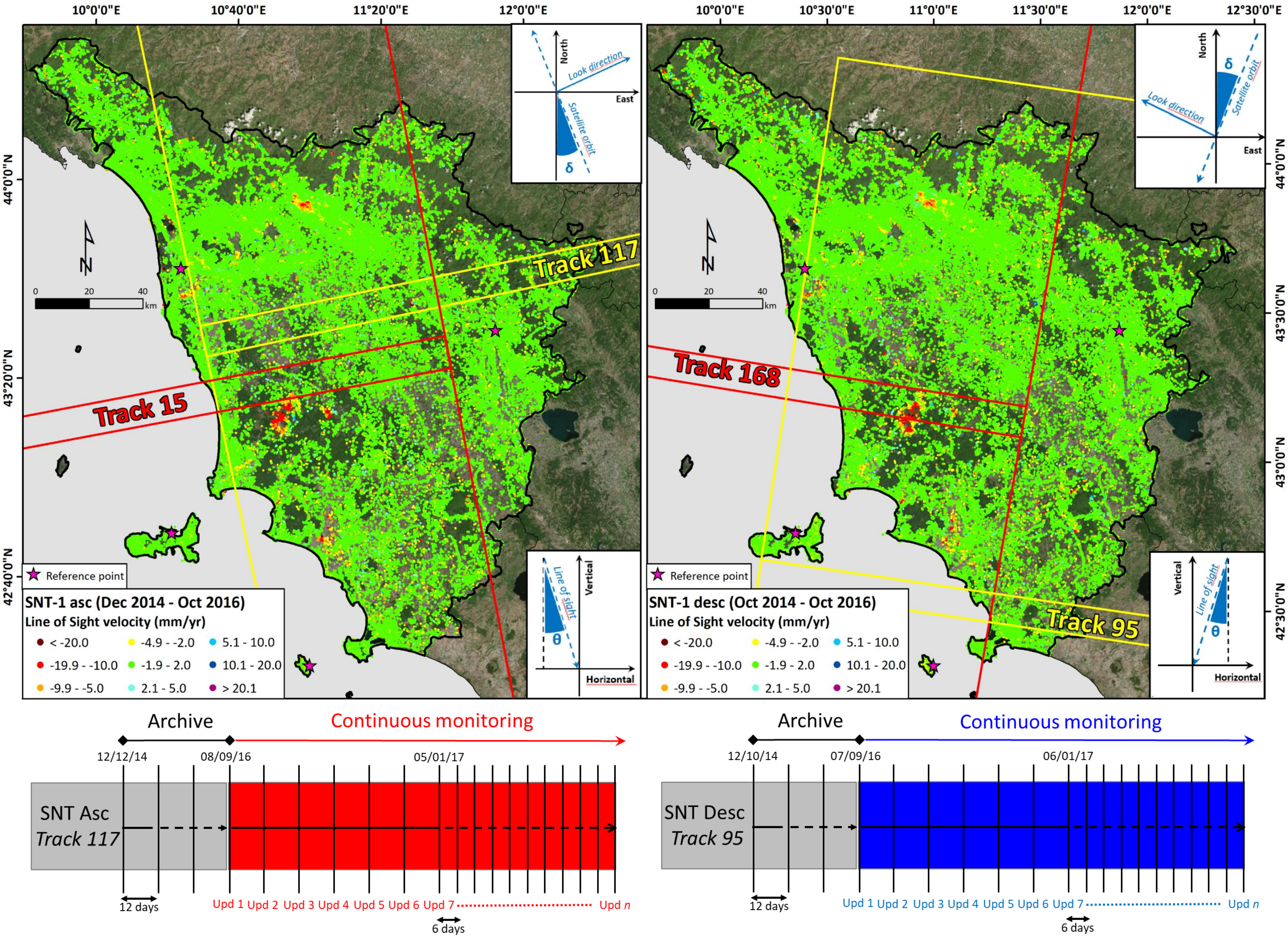
Veneto region



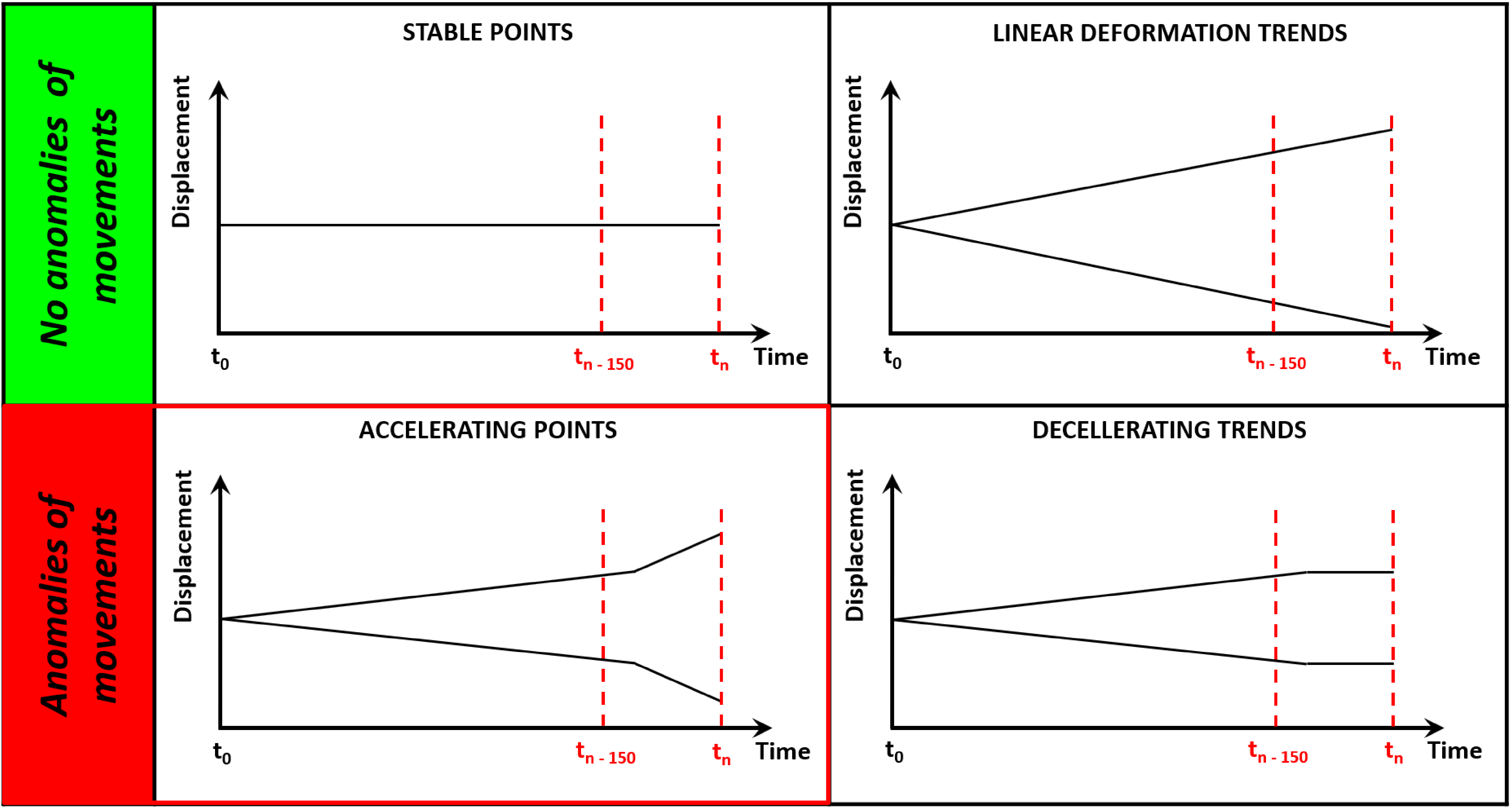
≈ 3.000.000 PSs

Transition from static satellite analysis, based on the processing of archive images, to dynamic monitoring of ground displacement

Sentinel-1 monitoring plans

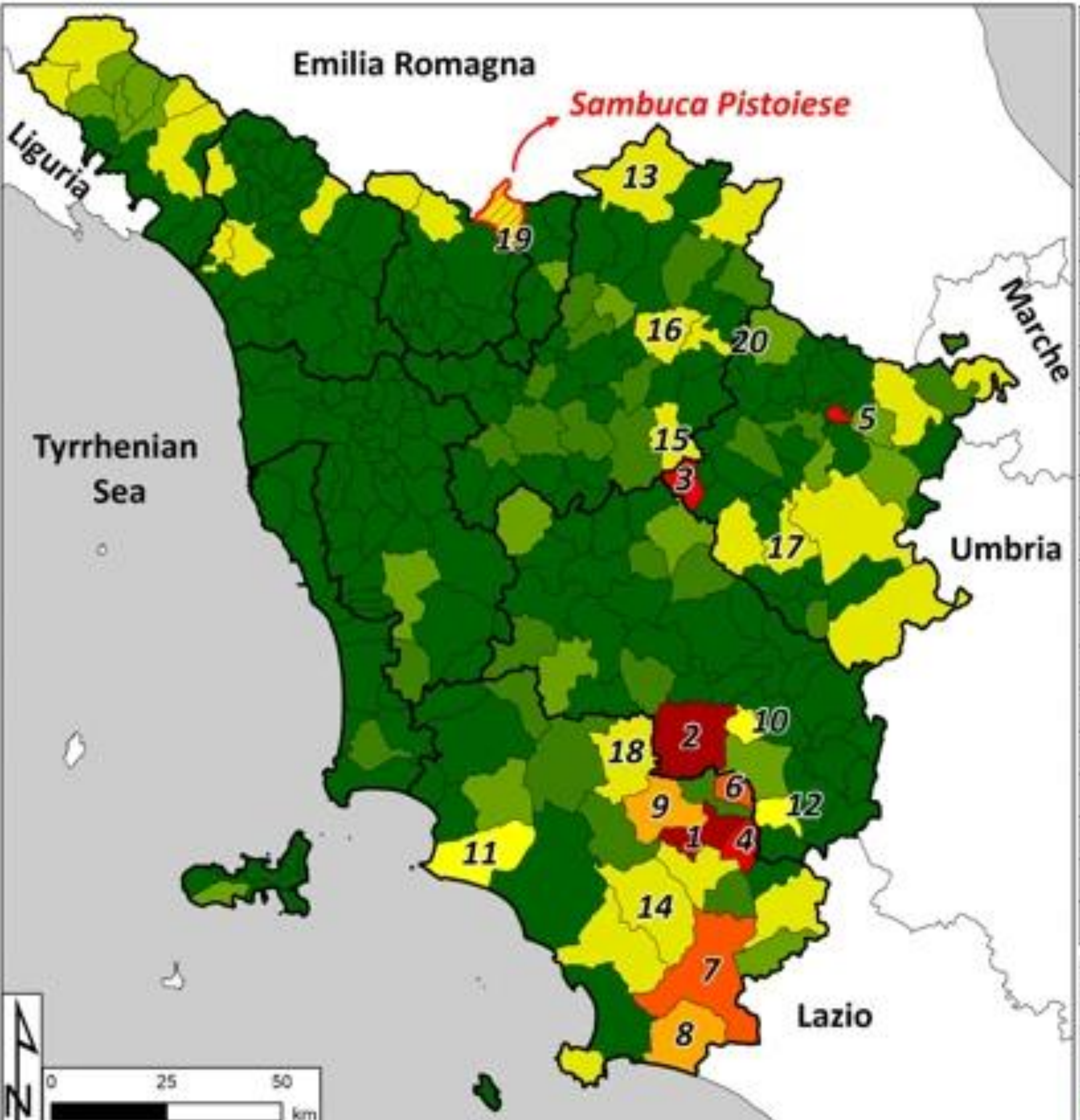


Trend variation analysis



Anomalouls point: MP whose time with a change of deformation rate in the last part of the time series (ΔV>10 mm/yr in the last 150 days)

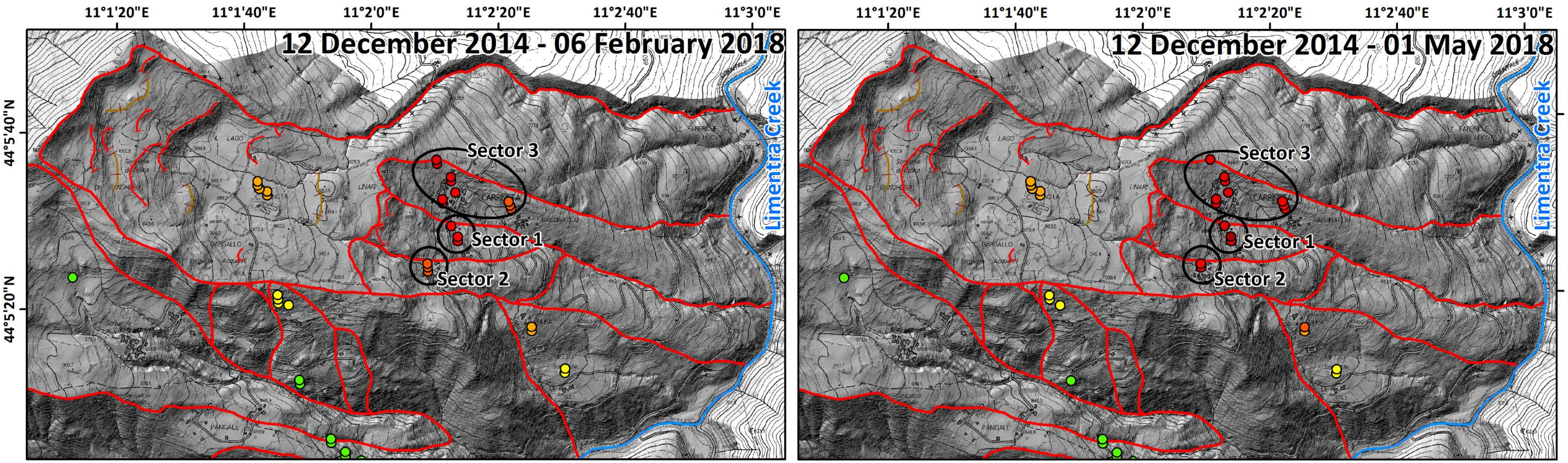
Landslide acceleration

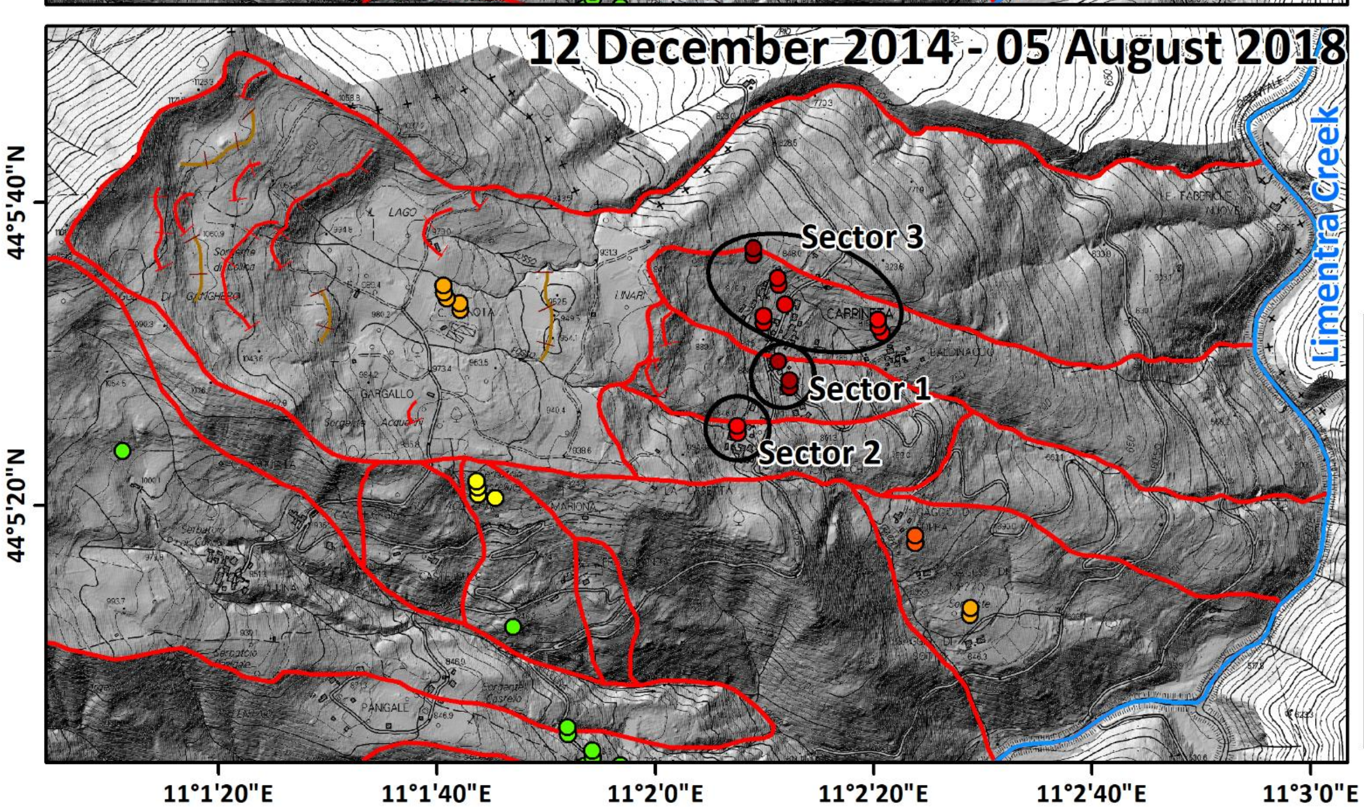


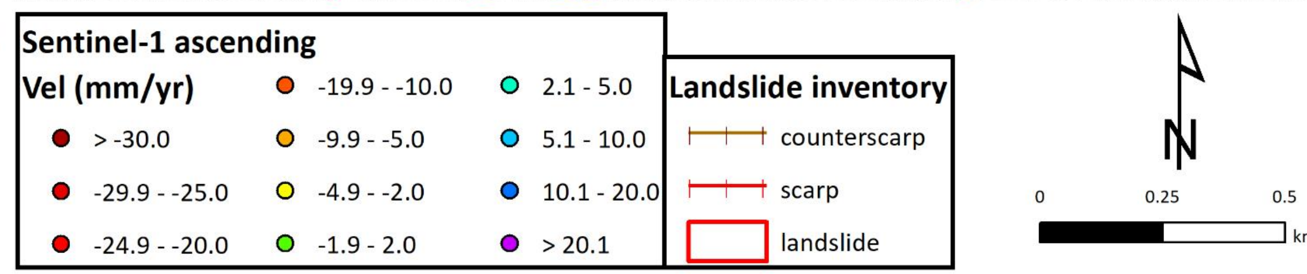
Label	Province	Municipality	# of persistent anomalies
1	Grosseto	Arcidosso	1333
2	Siena	Montalcino	1075
3	Arezzo	Cavriglia	995
4	Grosseto	Santa Fiora	793
5	Arezzo	Chitignano	550
6	Grosseto	Seggiano	382
7	Grosseto	Manciano	340
8	Grosseto	Capalbio	300
9	Grosseto	Cinigiano	281
10	Siena	San Quirico D'orcia	159
11	Grosseto	Castiglione della Pescaia	153
12	Siena	Abbadia San Salvatore	129
13	Firenze	Firenzuola	91
14	Grosseto	Scansano	90
15	Firenze	Figline e Incisa	89
16	Firenze	Pontassieve	88
17	Grosseto	Civitella in Val di Chiana	80
18	Grosseto	Civitella Paganico	79
19	Pistoia	Sambuca Pistoiese	78
20	Firenze	Rufina	76

Persistent anomalies (#): 0 - 10; 11 - 25; 26 - 50; 51 - 100; 101 - 200; 201 - 300; 301 - 500; 501 - 750; 751 - 1000; > 1000

Landslide acceleration

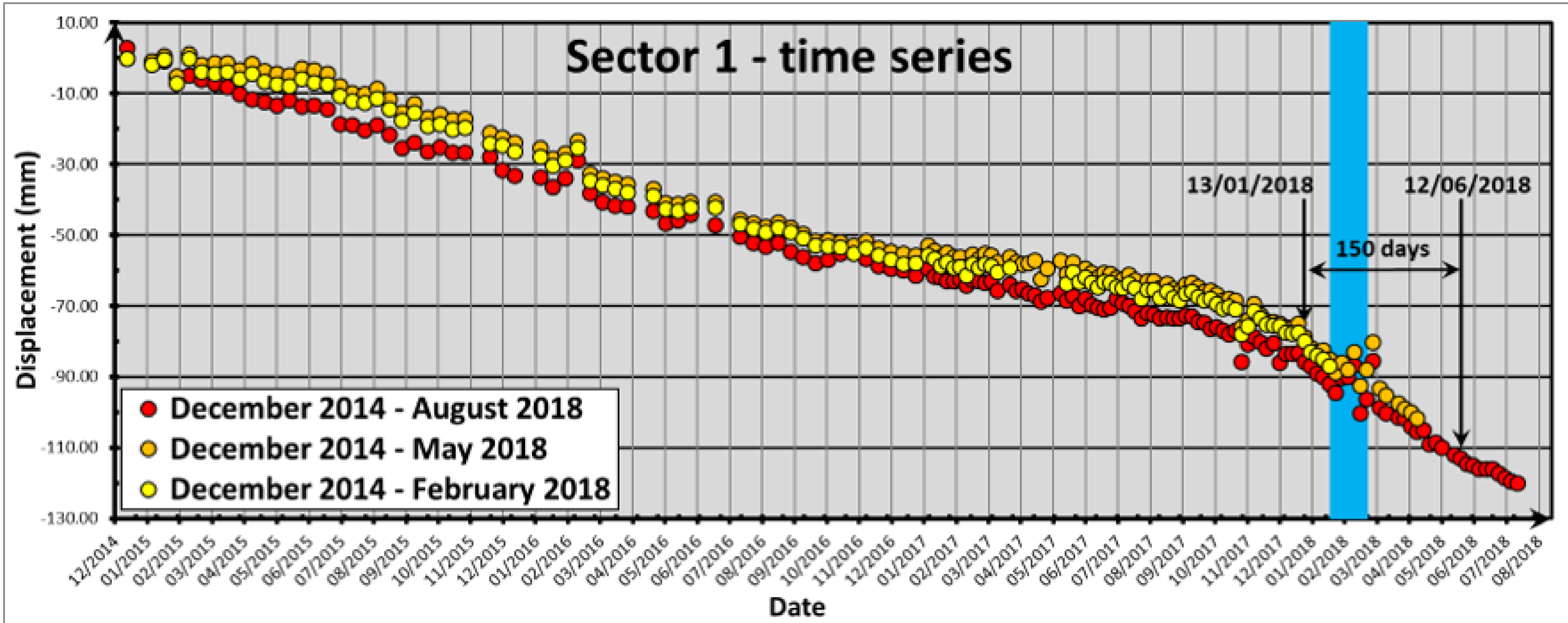






	12 December 2014 6 February 2018	12 December 2014 1 May 2018	12 December 2014 5 August 2018
Sector 1 Vel (mm/yr)	-24.6	-27.8	-30.2
Sector 2 Vel (mm/yr)	-19.4	-20.4	-22.1
Sector 3 Vel (mm/yr)	-23.9	-24.5	-26.4

Landslide acceleration



	Start of acceleration	Latency period	Appearance of anomaly	Disappearance of appearance	Persistency	Life length (days)
Sector 1	13/01/2018	4 acquisitions	06/02/2018	12/06/2018	126	150
Sector 2	12/02/2018	5 acquisitions	14/03/2018	06/07/2018	114	144
Sector 3	14/03/2018	3 acquisitions	01/04/208	05/08/2018	126	144

Conclusions

- SAR data represent a powerful tool for landslide analysis (i.e., mapping, monitoring and modelling)
- Interferometric approach are widely consolidates for the analysis of slow-moving slope deformations
- ESA Sentinel-1 constellation allow a regular and continuous monitoring of ground deformation at regional scale
- Transition from “one-shot” analysis of ground deformation to a sort of continuous monitoring at regional scale using satellite radar data is now possible
- An estimation of the failure time is possible, at least for some typologies of sliding phenomena

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Continuous, semi-automatic monitoring of ground deformation using Sentinel-1 satellites

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Federico Raspini[1], Silvia Bianchini[1], Andrea Ciampalini[1,3], Matteo Del Soldato[1], Lorenzo Solari[1], Fabrizio Novali[2], Sara Del Conte[2], Alessio Rucci[2], Alessandro Ferretti[2] & Nicola Casagli[1]

We present the continuous monitoring of ground deformation at regional scale using ESA (European Space Agency) Sentinel-1constellation of satellites. We discuss this operational monitoring service through the case study of the Tuscany Region (Central Italy), selected due to its peculiar geological setting prone to ground instability phenomena. We set up a systematic processing chain of Sentinel-1 acquisitions to create continuously updated ground deformation data to mark the transition from static satellite analysis, based on the analysis of archive images, to dynamic monitoring of ground displacement. Displacement time series, systematically updated with the most recent available Sentinel-1 acquisition, are analysed to identify anomalous points (*i.e.*, points where a change in the dynamic of motion is occurring). The presence of a cluster of persistent anomalies affecting elements at risk determines a significant level of risk, with the necessity of further analysis. Here, we show that the Sentinel-1 constellation can be used for continuous and systematic tracking of ground deformation phenomena at the regional scale. Our results demonstrate how satellite data, acquired with short revisiting times and promptly processed, can contribute to the detection of changes in ground deformation patterns and can act as a key information layer for risk mitigation.

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Perspectives on the prediction of catastrophic slope failures from satellite InSAR

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Tommaso Carlà[1], Emanuele Intrieri[1], Federico Raspini[1], Federica Bardi[2], Paolo Farina[2], Alessandro Ferretti[3], Davide Colombo[3], Fabrizio Novali[3] & Nicola Casagli[1]

We demonstrate the potential of satellite Interferometric Synthetic Aperture Radar (InSAR) to identify precursors to catastrophic slope failures. To date, early-warning has mostly relied on the availability of detailed, high-frequency data from sensors installed *in situ*. The same purpose could not be chased through spaceborne monitoring applications, as these could not yield information acquired in sufficiently systematic fashion. Here we present three sets of Sentinel-1 constellation images processed by means of multi-interferometric analysis. We detect clear trends of accelerating displacement prior to the catastrophic failure of three large slopes of very different nature: an open-pit mine slope, a natural rock slope in alpine terrain, and a tailings dam embankment. We determine that these events could have been located several days or weeks in advance. The results highlight that satellite InSAR may now be used to support decision making and enhance predictive ability for this type of hazard.

federico.raspini@unifi.it