Comparison Between PS and SBAS InSAR Techniques in Monitoring Shallow Landslides

Chapter · January 2021

DOI: 10.1007/978-3-030-60311-3_17

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Abstract	The main aim of this study is to compare the two commonly used multi-temporal interferometric synthetic aperture radar (InSAR) techniques, i.e. permanent scatterers (PS) and small baseline subset (SBAS), in monitoring shallow landslides. PS and SBAS techniques have been applied to ascending and descending Sentinel-1 SAR data to measure the rate of surface deformation and the displacement time series in the Rovegliana area (NE Italian pre-Alps) from 2014 to 2019. As expected, PS results cover only urban areas, while those obtained by SBAS cover up to the 85% of the investigated area. Velocity maps obtained by the two techniques show that some sectors of the investigated slope are affected by active shallow landslides which threaten the stability of buildings, walls and road network. The comparison between ascending and descending velocity maps along the satellite line of sight reveals the presence of a horizontal component in the east–west direction which is consistent with the landslide kinematic. The analysis of the displacement time series shows that, in the case of linear deformation trends, PS and SBAS results are similar, whereas, in the case of high oscillations and non-linear behavior, SBAS technique can provide a better estimation of the displacements. Besides, SBAS provides smoother and less noisy displacement time series. However, both the techniques showed their high capability in monitoring the evolution of the landslides, which is crucial for the implementation of effective risk prevention and mitigation strategies. To deep investigate the differences between the two techniques, other geomatic methodologies, based on global navigation satellite system and terrestrial laser scanning, should be used.

Keywords	DInSAR techniques - PS - SBAS - Sentinel-1 - Shallow landslides - Pre-alps - Italy

2020 Kyoto Japan

Comparison Between PS and SBAS InSAR Techniques in Monitoring Shallow Landslides

Xue Chen, Giulia Tessari, Massimo Fabris, Vladimiro Achilli, and Mario Floris

Abstract

The main aim of this study is to compare the two commonly used multi-temporal interferometric synthetic aperture radar (InSAR) techniques, i.e. permanent scatterers (PS) and small baseline subset (SBAS), in monitoring shallow landslides. PS and SBAS techniques have been applied to ascending and descending Sentinel-1 SAR data to measure the rate of surface deformation and the displacement time series in the Rovegliana area (NE Italian pre-Alps) from 2014 to 2019. As expected, PS results cover only urban areas, while those obtained by SBAS cover up to the 85% of the investigated area. Velocity maps obtained by the two techniques show that some sectors of the investigated slope are affected by active shallow landslides which threaten the stability of buildings, walls and road network. The comparison between ascending and descending velocity maps along the satellite line of sight reveals the presence of a horizontal component in the east–west direction which is consistent with the landslide kinematic. The analysis of the displacement time series shows that, in the case of linear deformation trends, PS and SBAS results are similar, whereas, in the case of high oscillations and non-linear behavior, SBAS technique can provide a better estimation of the displacements. Besides, SBAS provides smoother and less noisy displacement time series. However, both the techniques showed their high capability in monitoring the evolution of the landslides, which is crucial for the implementation of effective risk prevention and mitigation strategies. To deep investigate the differences between the two techniques, other geomatic methodologies, based on global navigation satellite system and terrestrial laser scanning, should be used.

Keywords

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Introduction

Differential interferometric synthetic aperture radar (DInSAR) is a powerful remote sensing technique for continuous detection and monitoring of land surface deformation, thanks to its cost-effectiveness and high-precision in the analysis of wide areas. In particular, this technique is capturing the attention of the landslide community in the last decades (Wasowski and Bovenga 2014). DInSAR uses a pair of complex-values SAR images, acquired at different time and from slightly different orbital positions, to generate an interferogram. The phase difference obtained from the two acquisitions can be converted into surface land displacement along the satellite line of sight (LOS) (Zeni et al. 2014). Multi-temporal interferometry methods, i.e. permanent scatterers (PS) (Ferretti et al. 2000, 2001; Crosetto et al. 2016) and small baseline subset (SBAS) (Berardino et al. 2002; Casu et al. 2006), overcome the limitation of DInSAR phase disturbance, such as atmospheric artifacts and topographic inaccuracies, leading to successful applications in

N. Casagli et al. (eds.), *Understanding and Reducing Landslide Disaster Risk*,
ICL Contribution to Landslide Disaster Risk Reduction,
https://doi.org/10.1007/978-3-030-60311-3_17

landslide investigations (e.g. Colesanti et al. 2003; Hilley et al. 2004).

PS-InSAR technique generates differential interferograms with one common master identifying persistent point-wise reflectors, such as manmade structures and rocks. It is generally applied to analyse deformation affecting urban areas, where the number of persistent scatterers is higher than in natural environments. This technique considers a deformation model (usually a linear model), avoiding phase filtering and unwrapping, simplifying the processing chain compared to the SBAS one.

SBAS-InSAR technique relies on a redundant network of image pairs, with short spatial and moderate temporal baseline, detecting the temporal evolution of the surface deformations and increasing the spatial coverage, especially over ~~nonurban~~ areas. This technique extracts the deformation time series from the observed filtered and unwrapped phases. Considering the much higher number of generated interferograms, this technique is more time-consuming from the computational viewpoint and for the operator intervention too.

In this paper, a comparison between the results obtained from PS and SBAS processing of Sentinel-1 data is reported, in terms of velocity maps and displacement time series, covering the time period 2014–2019. The analysis was carried out in an area affected by shallow landslides, located in the north-eastern Italian pre-Alps. In this area, previous studies (Tessari et al. 2017) have shown how interferometric analysis of several SAR datasets, including Sentinel-1A, represent a useful tool to investigate the instability phenomena.

Study Area

The study area, named Rovegliana, includes 4.2 km^2 wide unstable slopes located in the north-eastern Italian pre-Alps (Fig. 1). Several small agglomerates of houses are placed along the slopes facing to the Agno torrent. Elevation ranges from 800–900 m to 400–330 m a.s.l. and the average slope gradient is about 21 degrees.

The bedrock of the slopes is constituted by two heteropic formations deposited during middle Triassic: *Recoaro* limestone and *Gracilis* Formation. The first one outcrops in the upper part of the slopes and is composed by limestones, marly and dolomitic limestones. The second one outcrops in the middle and lower part of the slopes and consists of an alternance of sandy and marly limestones, interbedded with evaporitic dolomites. These formations are highly fractured due to the tectonic events that occurred during the Upper Triassic-Jurassic and the Alpine orogeny.

The whole area is prone to instabilities of alluvial and colluvial depositions resulting in large quantities of debris material with thickness up to 10 m. The grain size of the

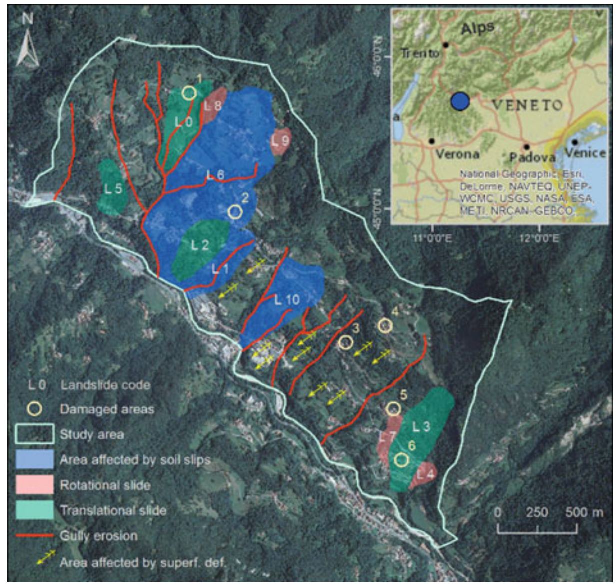

Fig. 1 Location of the study area (inset) and map of the main gravitational and erosional processes. The most damaged areas due to instability phenomena are indicated

debris is very heterogeneous, from millimetric to decametric clasts immersed in a clayey and silty sand matrix. Locally, morphological evidences, such as bumps, dips and sudden changes in the slope, reveal the presence of large boulders in the debris, dislocated from the calcareous formation located at the top of the area.

The slope instabilities were identified through in situ investigations, aerial photos interpretation and remote sensing surveys (GPS and DInSAR). They consist of translational and rotational slides, soil slips and superficial slow deformations (creep) which involve the debris cover (Fig. 1). Slide phenomena and soil slips have a high state of activity and mainly occur in the wet season (Autumn) after rainfall events (Toaldo et al. 2016; Tessari et al. 2017). Superficial deformations have displacement rates of few millimetres per year estimated by previous remote sensing surveys. They do not show clear geomorphological evidences, but movements result in damages (cracks) to buildings, walls and road network, and upward curvature of trees.

Data and Methods

Ground deformation over the study area has been measured using both ascending and descending Sentinel-1 C-band SAR images, acquired in interferometric wide swath mode, with a 12-day or 6-day revisit time and a spatial resolution of about 15 m. 216 images acquired from ascending track 117 (30 March 2015 to 04 November 2019) and 233 images acquired from descending track 95 (24 October 2014 to 03 November 2019) have been processed.

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The multi-temporal process of Sentinel-1 data has been performed through SARscape COTS, using both PS and SBAS algorithms. These approaches provide their best performances on different types of land cover and objects, point targets and distributed targets respectively (Pasquali et al. 2014).

The PS technique analyses the deformation of point scatterers with high temporal stability of the backscattered signal. It establishes a deformation model based on the phase difference of each pixel individually, without performing any phase unwrapping. This leads to preserving the maximum spatial resolution and the total independency of adjacent pixel measurements.

The SBAS technique measures deformations of distributed targets, e.g. sparsely urbanized areas and open fields. In fact, the volume decorrelation typical of natural distributed targets is reduced through an adaptive filtering step. The SBAS processing chain has been applied using an intermittent approach, which consists of extending the analysis to those resolution cells where the information has some temporal gaps because of the signal decorrelation, leading to coherence values smaller then the established acceptable threshold, equal to 0.3 in our analysis. Therefore, SBAS intermittent approach allows to spatially extend the final results. However, the results reliability is guarantee through two parameters establishing the minimum acceptable percentages of interferograms and images, to make sure that most of the deformation temporal information is preserved and directly calculated from the interferograms and using interpolation in the limited decorrelated temporal intervals. In detail, the analyses considered 60% as the percentage of interferograms and 95% as the minimum valid acquisitions, which means that pixels covering at least 60% interferometric connections of the whole connections and 95% acquisitions of all the acquisitions are maintained in the final result. All the pixels which were not respecting this controls have been discarded.

PS connection sets one image as the master, which is usually in the middle of the temporal and spatial distribution of acquisitions, in order to maintain a high coherence with most of the other images. The master image acquisitions for ascending and descending are 25 January 2018 and 25 November 2017, respectively. For SBAS connections, we set 36 days and 100 m as the temporal and spatial baselines constraints. In this case, we had to manually insert additional connections before the launch of Sentinel-1B, because of the low acquisition frequency of 12 days. Then, about 900 pairs were obtained.

We compared the results from PS- and SBAS- InSAR techniques considering spatial coverages, velocity distribution, capability of identifying landslides, and displacement time series.

Results

Ascending and descending velocity maps derived by PS and SBAS techniques are shown in Fig. 2. PS and SBAS results show different spatial coverage and quite similar displacement rates in the coinciding points.

PS points are mainly located in the small urban agglomerates or roads (see Figs. 2a, b and 1). The density of PS points in the entire study area is 262 per kilometres in ascending orbit and 437 per kilometres in descending. In the landslide areas, the density is higher, with 413 and 767 PS per kilometres in ascending and descending orbits, respectively. SBAS results cover most of the study area, providing information not only over anthropic structures but also on non-urban areas.

Results derived by the ~~processing~~ of ascending dataset cover the 85% (3.7 km) of the entire study area, those derived by descending track cover the 76% (3.2 km). Landslide areas are almost totally covered by both ascending and descending SBAS results.

The comparison between displacement rates estimated by the two techniques in all the coinciding points is reported in Fig. 3. The mean and standard deviation of difference values (SBAS velocity minus PS ones) are 1.99 and 2.17 for ascending, and -0.91 and 1.39 for descending datasets, respectively.

Considering the result coverage in the landslide areas, just one lanslides (L8) doesn't contain any PS both in ascending and descending orbit, while the others contain 4 or more PS with low variability in the estimated velocities (Tables 1 and 2). In the case of SBAS, more than 80% of landslide areas are covered by the results of the processing. In this case, the estimated velocities present quite high variability for each landslide and the mean values are generally significantly higher than those calculated by PS.

To compare the results from the two techniques, the displacement time series obtained by the processing of descending dataset in the most damaged areas have been considered (Fig. 4). In general, time series trends and shapes are very similar (Fig. 4b, c, and f), but SBAS series appear smoother and less noisy. PS and SBAS time series plotted in areas 1 and 4 (Fig. 4a and d) show differences in the displacement trends due to a divergence in deformation rate in the first part of the monitoring period.

Discussion

As expected, the SBAS technique provided a displacement rate estimation for a larger part of the study area ~~compare~~ to the PS one. However, both techniques provided very interesting information on the behaviour of the landslides

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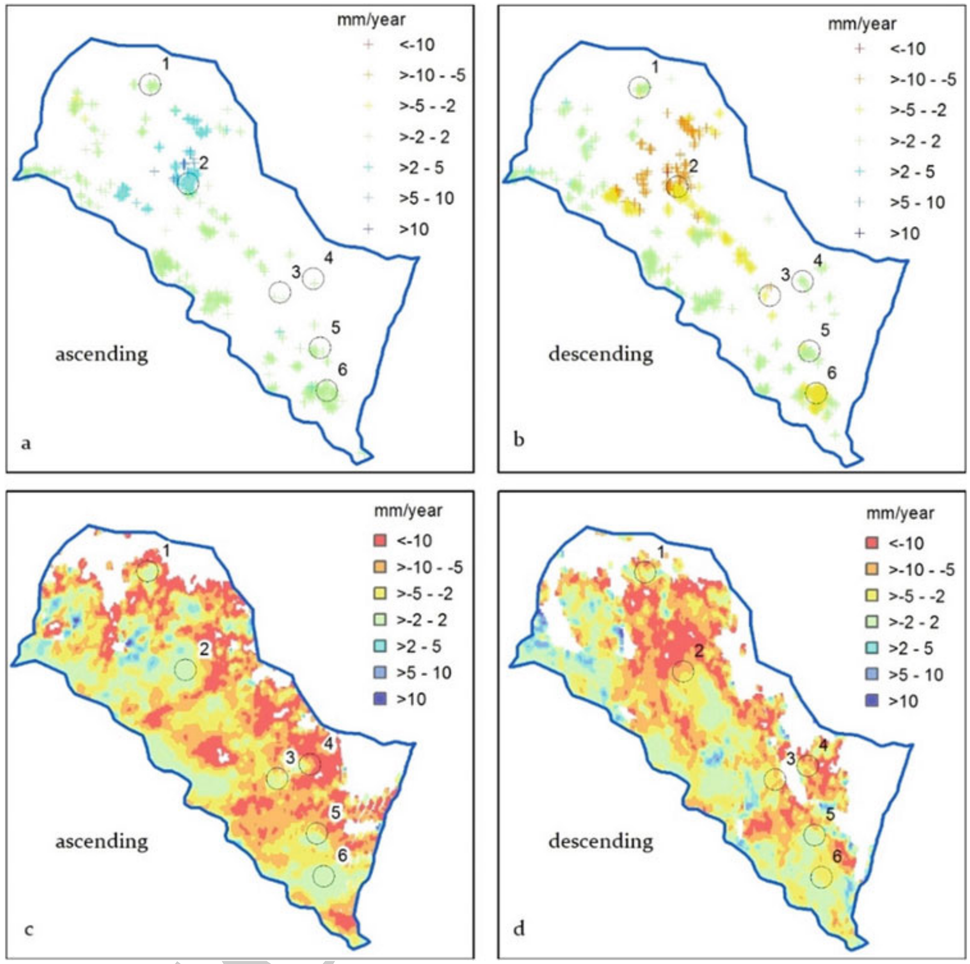

Fig. 2 Velocity maps derived by PS- (**a**, **b**) and SBAS- (**c**, **d**) InSAR processing of Sentinel-1 SAR data acquired in ascending (**a**, **c**) and descending (**b**, **d**) tracks. Black circles indicate the areas most damaged by instability phenomena

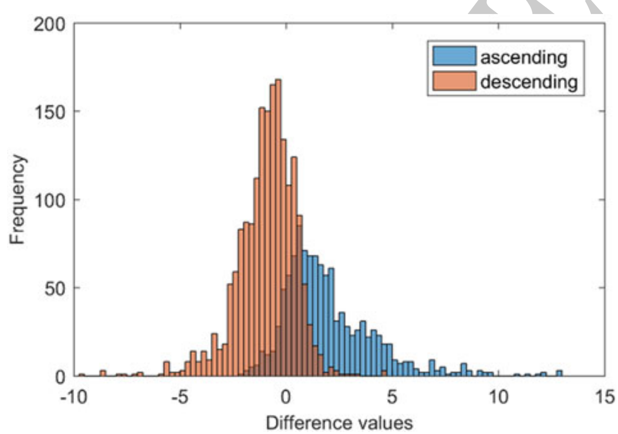

Fig. 3 Difference between velocities obtained by SBAS and PS techniques in all the coinciding points

affecting the investigated slopes. Both PS and SBAS results show that in the most active sectors of the area the displacements measured from ascending dataset are positive, while the descending ones are negative, which means that a horizontal component from east to west is present. These results are consistent with the landslide kinematic which mainly consist of superficial mass movements along the maximum slope direction, which has a dip toward the south-west of about 21°.

Considering the whole study area, the differences between the two techniques in the estimation of the displacements in the coinciding points are quite low (see Figs. 3 and 4) and caused by the different approaches. PS usually considers only a single pixel located in a building having an independent behaviour. Otherwise, SBAS measures a multilooked pixel which mediates the information of building with the surrounding area. In addition, SBAS includes a filtering step that makes the pixels spatially correlated.

Analysing each landslide, we found significant differences in the mean velocity and its variability. In particular, velocities estimated by SBAS are higher and show high variability. In the case of PS, only urban areas which are generally located on flat or gently slope, were detected, while SBAS provides the deformation rates of also non-urban and steepest sectors of the landslides which are generally higher. For this reason, SBAS technique can be considered more effective than PS in detecting and monitoring landslide phenomena.

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Table 1 Comparison between velocities estimated by PS and SBAS in landslide areas (ascending orbit)

Landslide		PS asc			SBAS asc		
Code	Area (km^2)	N. of points	Mean vel. (mm/y)	Std	Cover. (%)	Mean vel. (mm/y)	Std
0	0.100	53	0	0.5	100	−6.2	5.0
1	0.080	11	0.8	0.6	100	−6.0	3.6
2	0.080	8	1.7	0.9	100	−4.8	3.9
3	0.140	117	0.3	0.4	85	−4.1	4.4
4	0.020	4	0	0.6	77	−1.1	0.9
5	0.050	19	0.3	0.3	96	−3.1	2.5
6	0.500	220	3.4	1.3	90	−3.8	5.3
7	0.020	29	0.8	0.8	100	−2.2	1.5
8	0.002	0	-	-	100	−12.4	3.7
9	0.002	7	1.7	0.2	100	−7.9	3.0
10	0.150	28	0.8	0.3	94	−7.3	4.9

Table 2 Comparison between velocities estimated by PS and SBAS in landslide areas (descending orbit)

Landslide		PS desc			SBAS desc		
Code	Area (km^2)	N. of points	Mean vel. (mm/y)	Std	Cover. (%)	Mean vel. (mm/y)	Std
0	0.100	55	−0.6	0.4	96	−7.7	5.8
1	0.080	45	−0.2	1.3	100	−4.6	2.8
2	0.080	30	−2.7	1.2	100	−6.9	2.9
3	0.140	174	−2.1	1.1	79	−3.8	3.8
4	0.020	18	0.3	0.4	83	−0.2	2.4
5	0.050	39	0.3	0.6	85	−0.6	4.3
6	0.500	435	−5.2	2.3	89	−9.1	4.5
7	0.020	38	−0.4	1.7	100	−1.3	1.1
8	0.002	0	-	-	100	−5.5	4.4
9	0.002	8	−3.7	0.6	100	−6.5	3.2
10	0.150	80	−1.7	0.8	98	−2.0	3.3

Regarding the differences in the displacement time series obtained by the two techniques in the case of the damaged areas 1 and 4 (Fig. 4a and d), they can be due to the low frequency of acquisitions before the launch of Sentinel 1B satellite. The low number of SAR images can limit the potential of PS approach in detecting a non-linear trend of the displacement as occurred in the first part of the time series. Therefore, SBAS results should be considered more reliable.

Conclusions

In this study, we compared PS and SBAS InSAR techniques in monitoring shallow landslides affecting an area located in the north-eastern Italian pre-Alps. Both techniques provided very useful information on the landslides. But SBAS has shown better reliability in landslide detection and monitoring because of the larger coverage of the results and the ability to measure non-linear deformation patterns. Mass movements are often characterized by seasonal oscillations or accelerations, in this case, SBAS can provide smoother and more detailed displacement time series, leading to deeper insights on the temporal evolution of instability phenomena. SBAS allows monitoring both the landslides and the deformations of structures and infrastructures due to such phenomena, which is crucial for the implementation of effective risk prevention and mitigation strategies. However, also PS technique can provide information on the main landslide characteristics, but the results are mainly limited to urban areas, so that it can be considered as a very useful tool for the monitoring of the elements at risk.

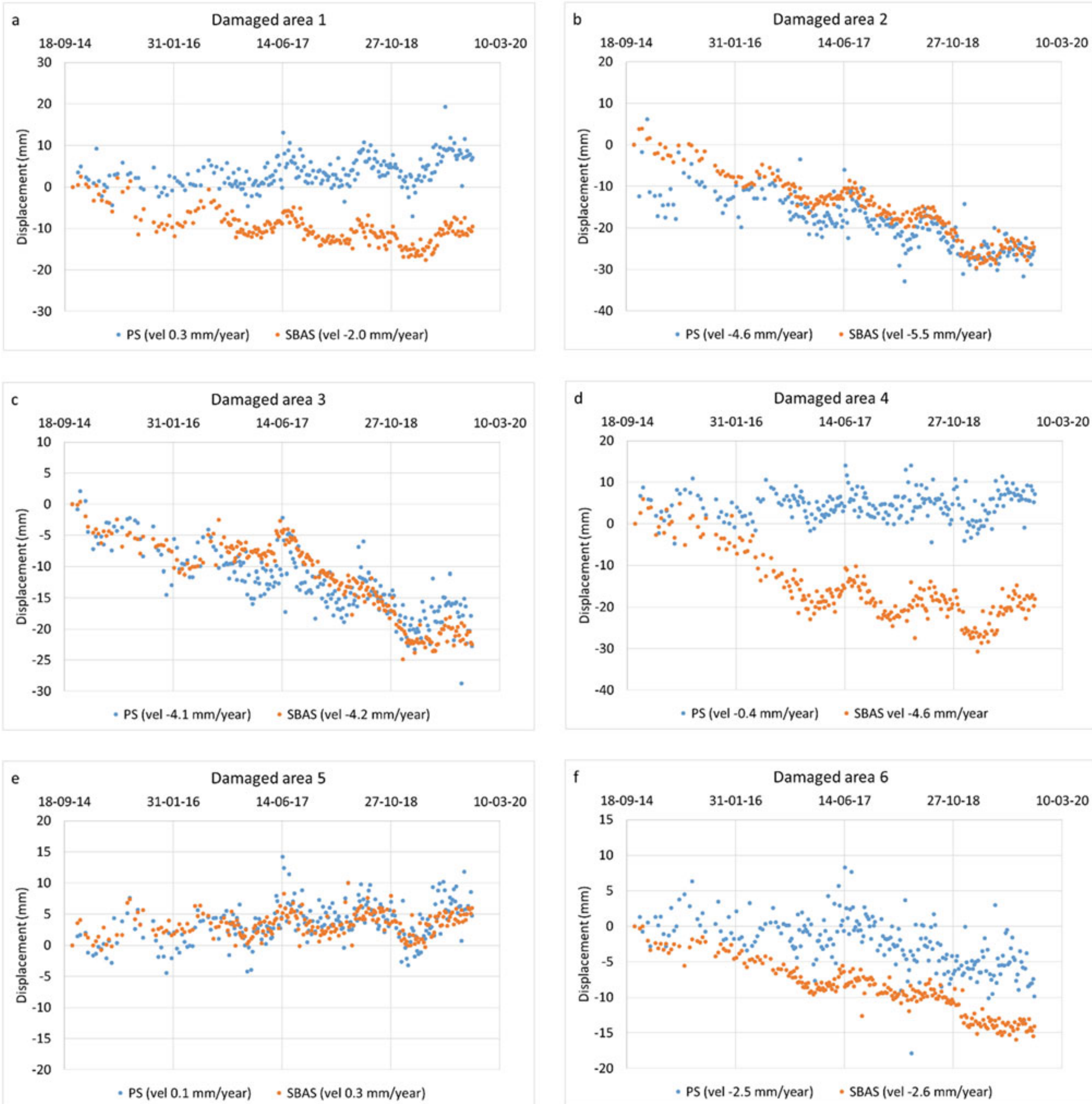

Fig. 4 Displacement time series derived by PS- and SBAS processing of descending Sentinel-1 data in the areas most affected by damages (location in Fig. 1)

In the next future, the obtained results will be integrated through ongoing GPS and terrestrial laser scanner surveys, to verify and, eventually, calibrate interferometry data and better understand the relationships between landslides and damages to anthropic structures.

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