MORFEO PROJECT: C- AND X-BAND SAR INTERFEROMETRIC ANALYSIS OVER ALPINE REGIONS (ITALY)

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ABSTRACT

In the present work we present first results of ground deformation measurements inferred through repeat-pass Synthetic Aperture Radar (SAR) Interferometry (InSAR) in C- and X-band over an Italian Alpine area, in Lombardia region. The activity was carried out in the framework of the MORFEO (*MOnitoraggio e Rischio da Frana mediante dati EO*) project, founded by the Italian Spatial Agency (ASI) and dedicated to landslide risk assessment. A number of areas affected by hydrogeological instabilities have been selected and studied in detail by processing both C- and X-band SAR data through SPINUA, a Persistent Scatterer like algorithm.
InSAR-derived displacements provided on areas of hydrogeological interest are going to be validated in the framework of MORFEO project by the geological partnership thanks to the availability of ground truths. In the present work, we present the results obtained for test sites around the towns of Garzeno and Bindo which are both affected by landslide phenomena. For the Garzeno case study we provide also a comparison between the deformation maps derived from ENVISAT and the preliminary results obtained with a limited number of COSMO-SkyMED images, as well as with ERS and RADARSAT PS maps freely available on the GeoIFFI web-catalogue.

Key words: Satellite Synthetic Aperture Radar; Persistent scatterers interferometry; COSMO-SkyMED.

1. INTRODUCTION

Thanks to the all-weather, day-night capability to detect and quantify accurately small ground surface deformations, Synthetic Aperture Radar (SAR) Interferometry (InSAR) techniques appear attractive for landslide hazard investigations and possibly for preliminary warning. MORFEO (*MOnitoraggio e Rischio da Frana mediante dati EO*) is a project founded by the Italian Spatial Agency (ASI), with the aim to develop and demonstrate, in a time-frame of three years, a system for landslide risk assessment dedicated to the Italian Civil Protection. One of the main innovative aspects of the project is the joint use of Earth Observation (EO) technologies and multi-mission satellite data, together with traditional *in situ* data and methodologies. In this framework, repeat-pass Differential SAR Interferometry (DInSAR) techniques are applied to detect and to measure ground displacement related to slope instabilities in a number of

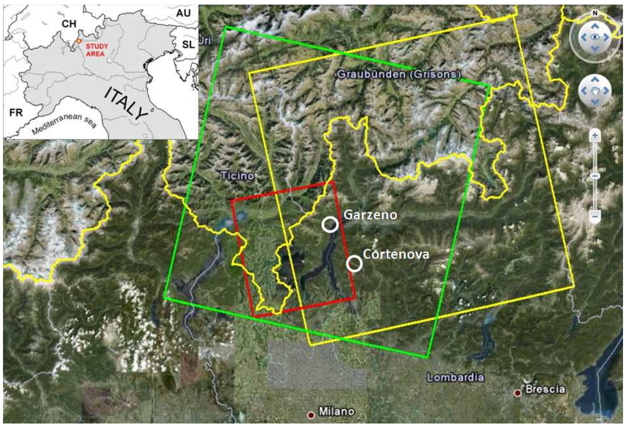

Figure 1. Yellow and green frames refer to the ENVISAT ASAR ascending and descending images ground coverage, while the red frame refers to the CSK acquisitions. Inset shows the location of the area of interest (AOI), that includes the towns of Garzeno (Province of Como) and Cortenova (Province of Lecco). Only one of the two case studies (Garzeno) is covered by CSK acquisitions.

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Alpine test sites affected by hydrogeological instabilities in Northern Italy (Fig.1). The areas of interest are located in the Provinces of Como (*Albano* and *San Vincenzo* river catchments), Lecco (*Bedolesso* Mountain, *Bindo-Cortenova* landslide in *Valsassina* Valley) and Sondrio (*Pruna* mountainous area, town of *Madesimo*). In this work we draw attention on two case studies shown in Figure 1 around towns of Garzeno and Cortenova case studies. First validation is also presented for Garzeno case study by providing geological considerations as well as by the cross-comparison of deformation fields obtained by different sensors (CSK, ENVISAT but also ERS and RADARSAT freely available on the GeoIFFI web-catalogue). For the Bindo-Cortenova study area no CSK images are available yet, but GPS campaigns allow a more comprehensive investigation of the local ground instabilities.

2. INSAR BACKGROUND

SAR interferometry allows to measure phase difference between the backscattered microwave signals received from slightly different positions [1]. This phase difference accounts for topography and, if the two SAR acquisitions are displaced in time, also for ground displacements occurred between the two acquisitions as well as for differences in atmospheric conditions [1].

When a series of SAR acquisitions is available over a test site, it is possible to combine them into several differential interferograms, which allow to follow displacement trends through time (multi-temporal DInSAR) and filter out both the atmospheric signal and the topographic residues. The detection precision of interferometric SAR data depends on the degree of correlation between the two complex signals which are combined to obtain each interferogram. Thus, displacement phenomena can only be followed with sufficient precision through multi-temporal DInSAR techniques on surfaces where coherence is maintained over long time scales (from months to years). Point-wise multi-temporal DInSAR techniques, known as Persistent Scatterers Interferometry (PSI), originally developed at *Politecnico di Milano* [2], constitute a valid investigation tool to maximize the precision with which displacement signals are detected via satellite-borne SAR interferometry. These methods rely on the identification and monitoring of objects that remain highly coherent through time. These coherent targets are called Persistent Scatterers (PS).

In favorable settings (e.g. urban areas containing many potential coherent targets such as buildings), and assuming the availability of a long temporal series of SAR images (generally not less than 20 in C-band [3]), PSI techniques allow to estimate and remove the atmospheric artifacts affecting the interferometric phase [1], and thus to detect with high precision small changes in Earth surface elevations. Where the PS density is high, displacement rate sensitivities along the Line of Sight (LOS) of the satellite between 1 and 3 mm/y can be achieved [3]. The situation is different when investigating displacements on scarcely urbanized areas, such as small villages on mountainous and rural zones affected by slope instabilities. Under these conditions the successful PSI applications is hindered due to different problems [5]: the objective scarcity of PS targets, the difficulty of detecting the few existing PS due to the pronounced atmospheric variations in regions with strong topographic relief, the limited spatial extension of landslides deformations.

Thanks to the finer spatial resolution with respect to C-band data, X-band InSAR applications appear very promising for monitoring single man-made structures (buildings, bridges, railways and highways) as well as area were last generation of C-band sensors showed low PS density. In this case, indeed, it is expected that many more man-made and natural targets will behave as persistent scatterers than in C-band. Moreover, thanks again to the higher resolution, it should be possible to infer reliable estimates of the displacement rates with a number of SAR scenes significantly lower than in C-band [3][6]. Finally, with shorter wavelengths the sensitivity to LOS displacements is increased together with the capability of detecting very low displacements rates (as the pre- and post-failure movements related to landslides are expected to be). The MORFEO system is thought and designed to exploit the use of X-band data provided by the COSMO-SkyMed (CSK) constellation for landslide monitoring. This represents a great opportunity w.r.t. previous experiments that uses C-band data for DInSAR applications to slope instability. The COSMO-SkyMed constellation will acquire data from its four SAR satellites in several imaging modes, to be processed into standard and higher level end products.

In particular, these new sensors provide spatial resolution[1] one order of magnitude better than the previous available satellite SAR data, as well as short revisit time (up to 8 hours for the full constellation). A difference in the incidence angle between two interferometric acquisitions causes a spectral shift between the signal spectral bands proportional to the effective (normal) geometrical baseline. When the normal baseline equals the so-called *critical baseline*, the spectral shift equals the signal radar bandwidth and the signals are totally decorrelated [9][10]. In spite of a shorter wavelength ($\lambda \approx 3cm$ in X-band, $5.6cm$ in C-band), the tenfold improved spatial resolution along ground range direction ensures *critical baseline* values 5÷6 times higher than in C-band, thus reducing in theory the effects of the geometrical decorrelation, for a given interferometric SAR geometry.

Furthermore, the faster revisit of the same Area of Interest (AOI) of the actual X-band missions[2] counterbalances the negative effect of the shorter wavelength on the temporal decorrelation [9]. In the present work we experiment the use of CSK X-band SAR data for PSI application to landslide study. In particular, we try to demonstrate the increased capability in deformations

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[1] Spatial resolution ranges from *~3m* for COSMO-SkyMED missions (stripmap single POL acquisition mode), till *~30m* for the C-band ERS/ASAR sensors

[2] T*he orbital repeat cycle* δt is equal to 35 days for ESA missions, 11 days for TerraSAR-X, 16 days for each COSMO-SkyMED satellite (only 4 days when the COSMO-SkyMED constellation will be fully operative).

measurement thanks to the combined use of ENVISAT C-band and CSK X-band SAR data, despite the number of CSK acquisitions is quite limited.

The SPINUA (Stable Point INterferometry over Unurbanised Areas) algorithm has been used for performing repeat-pass interferometry. The processing chain is the result of a joint effort of the Remote Sensing Group of the Department of Physics at *Politecnico di Bari* and the ISSIA-CNR institute of Bari. The SPINUA PS-InSAR technique has been developed with the aim of detection and monitoring of coherent PS targets in non- or scarcely-urbanized areas. A complete description can be found in [4]. The processing chain has been further updated in order to deal properly with X-band data from both CSK and TerraSAR-X.

3. THE BINDO-CORTENOVA LANDSLIDES

3.1. Background information

The first study area is located to the east of the Lake of Como (Figure 1) in the Central Italian Alps and it is characterised by a pre-alpine landscape with maximum elevation of 3000 m a.s.l.. It consists of steep slopes with different bedrock lithologies, complex structural settings and evidences of past glaciations, such as U shape valley profiles, glacial deposits, suspended and undercut alluvial fans, and suspended valleys, etc [12]. The average annual precipitation in the study area can be considered relevant, ranging between 1300 and 2100 mm. On average, the most intensive rainfall season is generally in May with the average monthly precipitations between 160 and 190 mm. Nevertheless, November 2002 was one of the higher precipitation periods with 493 up to 875 mm of measured cumulative rainfall. It triggered numerous large landslides in the Central Italian Alps [12]. A 1.2 million m^3 debris avalanche failed in December 2002 on the village of Bindo (Cortenova, Italy), and disconnected rock mass from the toe of the relict landslide, covering a slope sector of about 85000 m^2 and destroying 17 houses and interrupting industrial activities for several weeks. A large portion of slope is still active and threatens the remnant part of the village.

3.2. GPS campaign

Since the end of 2003, a GPS monitoring network was installed on the area involved by the Bindo landslide by the local authorities with the consulting of the University of Milano-Bicocca. The network consists of 4 geodetic-quality, dual-frequency GPS receivers, whose location is shown in Figure 2. The master receiver, named RR2, has been installed on the Valsassina Valley, while the 3 remaining measurement GPS stations (named B1, R28 and R32) have been placed at the top of the failed area, as visible in Figure 2.

The GPS observations were processed by using the Bernese software at the geomatics laboratory of the *Politecnico di Milano*. The software performs a least squares adjustment of a linear combinations of phase observations between couples of receivers to couples of satellites, the so called double difference, allowing for the estimates of the differences between the cartesian coordinates of the two stations involved in the combination: the baseline components. The software let the user choose the baseline to be estimated. For the Bindo case a baseline star shaped configuration was chosen, all the baselines stemming from the master RR2 receiver. Once the master station coordinates are fixed, the position of the other points can be retrieved from the estimated baselines components. The master stations coordinates were estimated with respect to the 3 nearest stations of the Lombardia GPS permanent network. The estimated coordinates of 4 weeks of daily adjustments were considered to verify the stability of the master position in time, with respect to the Lombardia reference network. The averages of the 3 coordinates time series were then used as fixed coordinates in the Bindo network adjustment. As for the ambiguity resolution, although in the local network adjustment it is suggested to apply the sigma method, the QIF technique was chosen as it gave the best results, in terms of posterior sigma note. Finally, 12 hours sessions were adjusted at a time.

3.3. Interferometric processing

Two stacks of ENVISAT SAR images (Swath IS2, Incidence Angle @ mid-range: 23°), acquired between October 2004 and January 2009, have been independently processed through the SPINUA algorithm. One dataset consists in 30 ascending Single Look Complex (SLC) acquisitions (Track 215, Frame 927), while the descending dataset amounts to 32 SLCs (Track 480, Frame 2673). In Figure 1 it is shown the ground coverage of both frames, while the estimated ground displacement rate map along descending Line of Sight (LOS) is shown in Figure 2. Steep slopes and layover effects prevent the investigation of the study area with ascending acquisitions.

3.4. Results from Cortenova test area

Because of the thick vegetation, Persistent Scatterers cannot be detected close to GPS stations located at the top of the failed area. ENVISAT displacement rate map well covers instead the depletion zone of the Cortenova landslide, where the soil is mostly bare and no GPS stations were installed.

Detected LOS downward movements at the foot of the landslide are not exceeding 20 mm/yr (Figure 3), while GPS station named as B1 in Figure 2 measures a relative much faster vertical movement wrt the master receiver RR2 (as shown in Figure 4), that reaches 30 cm in only 3 years (2004÷2007), thus confirming the rapid retrogression of the landslide.

The selected case study represents therefore a good example on how the integration of GPS and SAR measurements may play an important role for a proper understanding of the geophysical phenomenon in act in the area.

4. THE TOWN OF GARZENO CASE STUDY

4.1. Background information

The second study area is located in the western flank of

Lake Como (nearly 15 km^2) and comprises the lower Albano river catchment. Rocks outcropping in the area belongs to Southern Alps basement, and consist mainly of paragneiss and schist. The Albano river basin is characterized by steep slopes with large deep-seated landslides on the both sides of the valley (as depicted in Figure 5). In particular, landslides affecting the northern slope induce damages to buildings and infrastructures in Garzeno and Catasco villages. Although the presence of long-term damages, the landslide complex has been identified and mapped only recently, and was not studied systematically. Last year, monitoring activity was started in the Catasco village, where recently inclinometer probes have detected ground surface movements of around 10 mm/yr. The instability is characterized by a large landslide body which is partially active, with movements mostly localized in the eastern part of the villages. The area is also frequently interested by shallow landslides developed within the debris deposit of the main landslide body.

4.2. Interferometric processing

The two stacks of ENVISAT SAR images processed for investigating the landslide of Bindo-Cortenova also cover the Garzeno and Catasco villages. In the latter case study, however, thanks to the different slope orientation of the AOI, multi-temporal interferometric analyses may be accomplished along both ascending and descending LOS. The estimated ground displacement rate maps are shown in Figure 5. The two processed stacks ensure the detection of movements occurring along both west and east facing slopes.

Moreover, a first multi-temporal interferometric analysis in X band has been carried out through the SPINUA algorithm by processing a set of 12 CSK ascending HIMAGE interferometric acquisitions (Satellite CSKS1; Beam HI-03; POL: HH; Incidence Angle: 27.7°÷31.0°, from near to far range) provided by the Italian Spatial Agency (ASI). The CSK dataset is listed in Table 1, while ground coverage of the CSK frame is drawn in red on Figure 1. All provided CSK SLCs are labeled as SCS_U[3]. An initial azimuth filtering has been therefore applied in order to be confident that azimuth ambiguities (*ghosts*) have been mostly removed.

X-band SAR data require some ad hoc processing solutions. The more relevant concerns the image alignment is a crucial step in the interferogram generation process, since 1/8 pixel accuracy is required to avoid significant loss of interferometric phase coherence [1]. In case of rough topography and long baselines, standard coregistration methods, based on 2D polynomial modeling of the warp functions, becomes inaccurate, leading to local misregistrations. These effects increase with the spatial resolution and then with the sampling frequency of the sensor [7], thus becoming more tricky in X-band than in C-band. An improved, DEM-assisted image coregistration procedure should be adopted in all these cases for providing higher-order prediction of the offset vectors [7]. CSK images have been therefore aligned through a DEM-assisted coregistration approach developed at TU Delft [8], since the sub-pixel accuracy needed for a proper interferogram generation cannot be ensured in this context by the conventional alignment methods, because of the CSK high spatial resolution, together with the rough topography of the Alpine test site. Furthermore, while the TSX diameter of the nominal orbital tube guarantees normal baselines rarely exceeding 250m [6], effective baselines between CSK interferometric acquisitions may be even close to 1km, as shown in Table 1. DEM-assisted approach for CSK images alignment is therefore absolutely required in this case [5]. The CSK image acquired on February 10, 2009 has been chosen as master, since it minimizes the distance w.r.t. all the other images in the ($B_t;B_n$) space, where B_t and B_n are the temporal and normal baselines.

Doppler centroid frequencies, f_{Dc}, of all the CSK acquisitions are listed in Table 1. Significant shifts between the spectral bands in the azimuth direction of the master and slave acquisitions represent another source of decorrelation of the interferometric phase [11]. For ERS missions, azimuth spectral shift can be significant for interferograms between ERS-1 and ERS-2 acquisitions as well as ERS-2 / ERS-2 interferograms with images acquired after the failure of the gyroscopes of ERS-2 occurred at 7 February 2000. Similarly, SAR images acquired by different sensors of the COSMO-SkyMED constellation generally could have f_{Dc} values much distant from each other. In our case, although Doppler centroid frequencies are not constrained in few tens of Hz, differences among them are quite negligible if compared with the Pulse Repetition Frequency (*PRF=3.06 kHz*), as expected when all the acquisitions comes from a single satellite of the CSK constellation, thus not worsening the interferometric coherence.

Thanks to the higher resolution of new generation of X-band SAR, it should be possible to infer reliable estimates of the displacements with a number of SAR scenes significantly lower than in C-band. A first experiment carried out with TerraSAR-X data on strongly urbanized small areas [6] confirmed that by using even less than 15 SAR acquisitions it is still possible to reliably infer displacement rates. Thus, in the present case, the number of 12 CSK acquisitions (August 2008 – June 2009), which would have been unacceptable in C-band, seems to be still enough to try a preliminary InSAR multi-temporal analysis over the towns of Garzeno and Catasco. Although we deal with more complex settings of the test area (due to steep topography and vegetation coverage) w.r.t. the case of study in [6], the results appear encouraging and in the following we provide a cross-comparison with those obtained by processing C-band.

4.3. Results from Garzeno test area

A first validation of the ENVISAT displacement rate maps has been carried out by comparing them with the PS maps previously obtained by T.R.E. s.r.l. in the framework of the GeoIFFI project by processing ERS-1/2 SAR images acquired in a ten-year time-frame

[3] SCS_U: focused data, unweighted and not radiometrically equalized

(1992-2001), freely browseable on the GeoIFFI web-catalogue [14]. Even if the ERS and ENVISAT datasets do not share a common time interval, the comparison shows a good agreement. A more significant cross-validation could be accomplished with the RADARSAT T.R.E. PS maps, also available in the GeoIFFI web-catalogue, covering the 2003-2007 time frame, thanks to the temporal overlap with the ENVISAT datasets, but the quite different incidence angle of the RADARSAT acquisitions (Standard Beam S3; Incidence Angle: 30.4°÷36.9°, from near to far range) should be taken into account.

Because of the *side looking* acquisition mode of a SAR sensor flying on a quasi-polar orbit around the Earth and then its poor sensitivity to movements along North-South direction (N-S cosine director of the LOS is indeed usually negligible), InSAR techniques are in general not optimally suited for monitoring displacements occurring along North-South facing slopes. Nevertheless, ENVISAT confirms the actual landslides activity in the northern slope of the Albano river basin. Persistent Scatterers detected over Garzeno and Catasco villages registers ground displacement rates close or even exceeding 1 cm/yr along the ascending line of sight (top of Figure 5). The increasing PS density from the western to the eastern part of their urban areas can be explained in terms of different facing slope, ranging from South-South West (SSW), at West, to South-South East (SSE), at East. Also the town of Germasino is affected by hydrogeological instabilities (top of Figure 5), but displacement rates estimated through InSAR measurements are less intense in this case (up to 3÷4 mm/yr).

Because of the steep ENVISAT incidence angle, SAR distortion effects (foreshortening) heavily affect the western part of the Garzeno and Catasco villages in the ascending ENVISAT displacement rate map, thus determining a lack of PS, as confirmed by the GeoIFFI ERS maps. Differences in PS densities and displacement rates between ascending and descending ENVISAT acquisitions over the selected AOI (resp., at the top and bottom of Figure 5), also confirmed by the GeoIFFI catalogue, can be still explained in terms of different LOS sensitivity to down-slope movements, according to the test site geomorphology.

For Garzeno and Catasco villages, the preliminary X-band analysis confirms the landslide activity affecting these urban areas (Figure 6). Although the number of CSK acquisitions is quite limited, spanning a period of only 10 months (August 2008 – June 2009), SPINUA was capable to retrieve preliminary ground displacement patterns. The higher incidence angle of the H4-03 beam reduces the effect of SAR geometric distorsions in the CSK ascending acquisitions, thus allowing the detection of PS even in the western part of the towns. Such an explanation is confirmed by the GeoIFFI RADARSAT PS maps, where the uniform PS density over the Garzeno and Catasco urban areas may be still explained in terms of the higher incidence angle of the RADARSAT standard beam S3 with respect to the ENVISAT IS2 swath. Anyway, it can be appreciated the higher spatial resolution which in turn leads to higher PS spatial density.

As mentioned before, the recent *in situ* ground monitoring activity identified, around Garzeno and Catasco villages, a large landslide body only partially active, with movements mostly localized in the eastern part of the villages. This could explain the gradient in the CSK displacement rate map, when moving from the western part (almost stable) to the eastern part (more unstable) of these villages. This gradient is also well confirmed by the RADARSAT ascending results, but only partially visible in the ERS/ENVISAT data because of the lack of PS on the western urban areas, as discussed before. Anyway, it should be noticed that the SAR sensitivity to down-slope ground movements could be much different, depending on the slope orientation. In particular, for the selected case of study and for the CSK ascending LOS, DInSAR measurement sensitivity to ground movements occurring along SSW oriented slopes is quite worse than along SSE direction, thus likely contributing to the differences in the measured displacement rates.

CONCLUSIONS

In the framework of the MORFEO project, we applied the SPINUA algorithm to infer ground deformation measurements over a number of test sites affected by hydrogeological instabilities. In the present work, we draw attention on two selected Alpine areas, in Lombardia region (Italy).

The first case study is located to the East of the Lake of Como, near Bindo village, where a 1.2 million m^3 debris avalanche failed in December 2002. The GPS campaign, started just after the failure, as well as the ENVISAT PS-InSAR monitoring, represent a good example of how the integration of GPS and SAR data may contribute together for a better understanding of the actual evolution of the landslide activity.

About the second area of interest, also affected by landslides, involving Garzeno, Catasco and other neighboring villages located in the Albano river catchment, both C- and X-band PS processing was carried out, providing displacement maps that seems in agreement with the first *in situ* ground truths, provided in the framework of a monitoring campaign recently started over Catasco. Moreover an encouraging cross-comparison has been carried out with ERS and RADARSAT C-band deformation maps freely available on the GeoIFFI web-catalogue.

This experiment confirms that, because of the tenfold improved resolution of X-band images, multi-temporal InSAR techniques may be successfully applied for the estimation of the displacement maps with a number of acquisitions much lower than in C-band. The consistent results also show the good performances of the SPINUA PSI processing chain. Anyway, further investigations are necessary in order to confirm the preliminary results so far derived in X-band. This should be possible when a consistent number of CSK acquisitions would be available over the selected AOI.

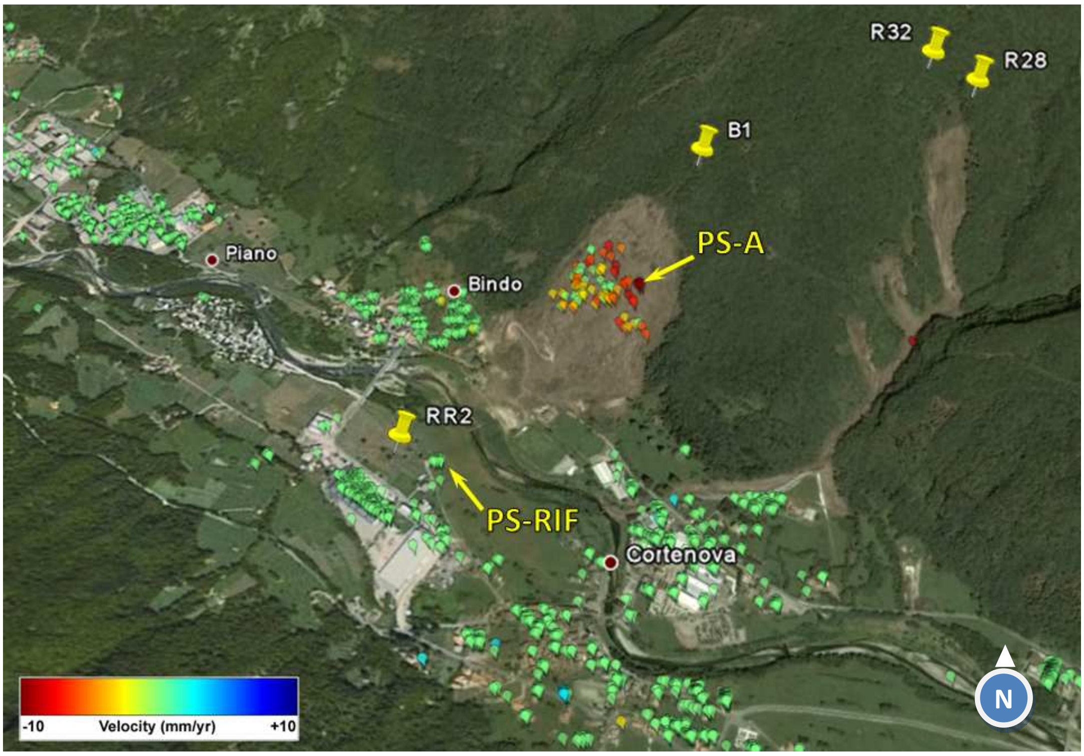

Figure 2. Case study: Cortenova (LC). SPINUA displacement rate map estimated by processing the ENVISAT descending dataset consisting of 32 SLCs (Track 480, Frame 2673), acquired between December 2004 and January 2009. Background optical image is from Google Earth ©. The average Line of Sight (LOS) velocity has been saturated at ±10 mm/yr for visualisation purposes. The location of GPS stations is given by the yellow placemarks, while yellow arrows point to selected Persistent Scatterers whose displacement trends are shown in Figure 3.

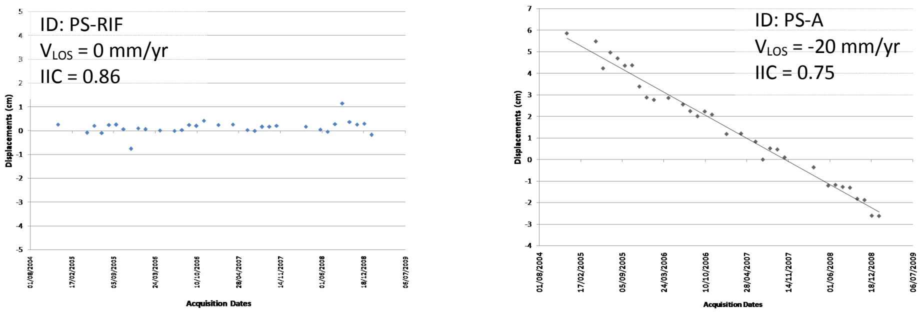

Figure 3. Case study: Cortenova (LC). LOS displacement trends measured by SPINUA for Persistent Scatterers named as PS-RIF (left) and PS-A (right), spanning the period December 2004 ÷ January 2009 (ENVISAT descending dataset – Track 480, Frame 2673). The ground location of the selected PS is shown in Figure 2.

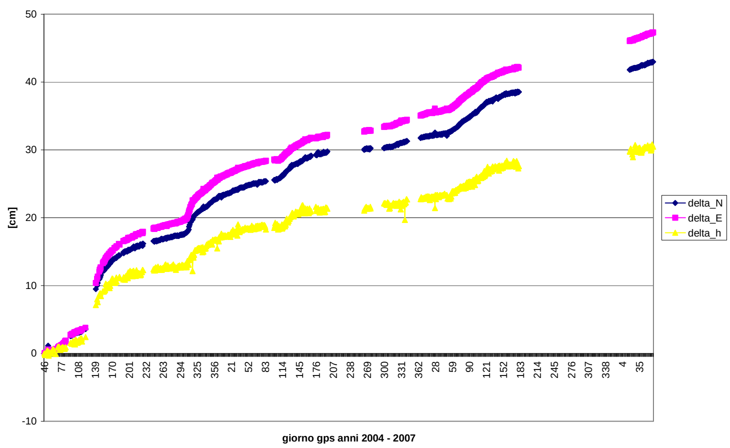

Figure 4. Case study: Cortenova (LC). Relative GPS displacements observed between the B1 GPS station and the master RR2 receiver. Up to 30 cm of vertical displacements have been measured from Feb. 2004 to Feb. 2007

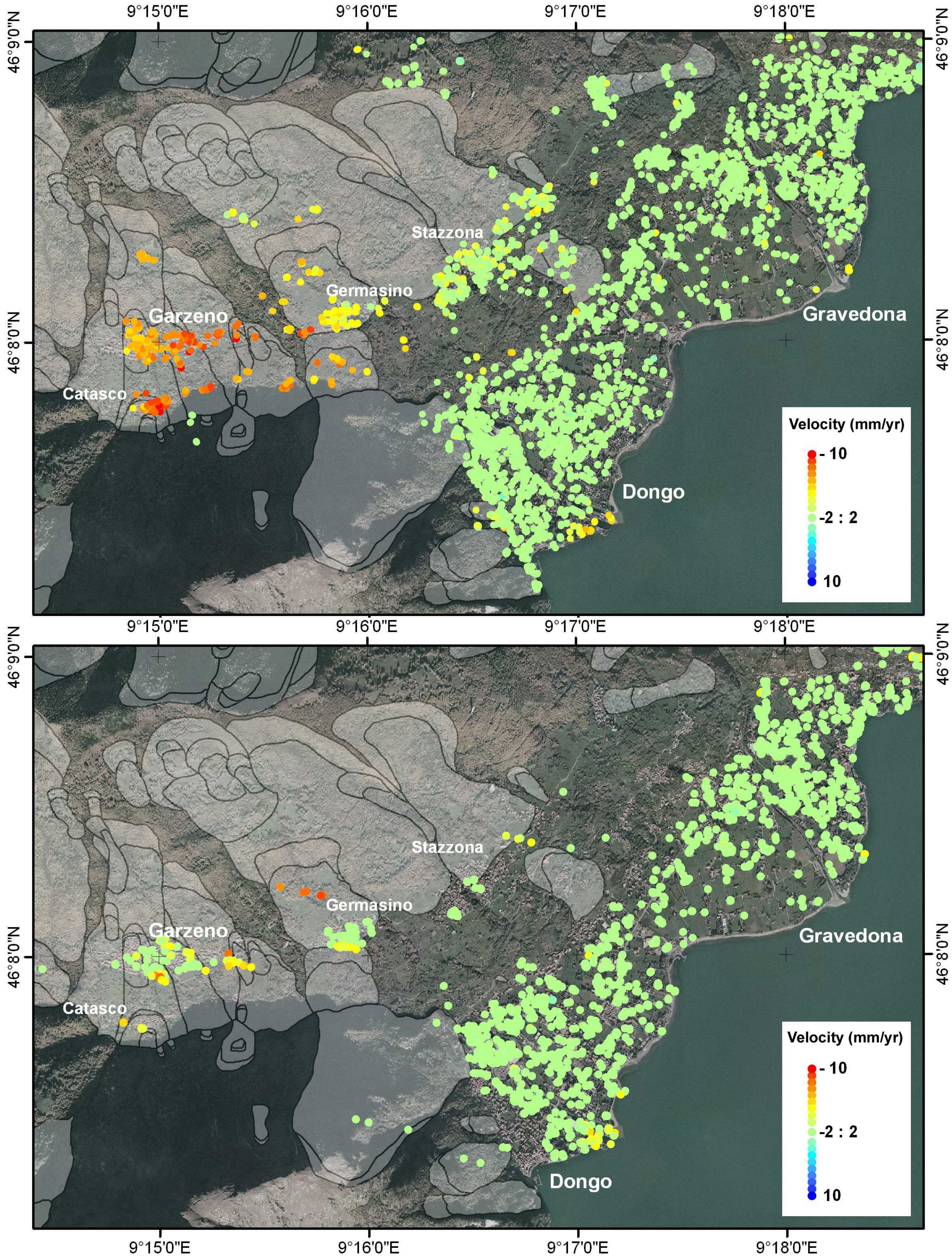

Figure 5. Case study: Garzeno - Catasco (CO). (Top) SPINUA displacement rate map estimated by processing the ENVISAT ascending dataset consisting of 30 SLCs (Track 215, Frame 927), acquired between October 2004 and January 2009. (Bottom) SPINUA displacement rate map obtained by processing the ENVISAT descending dataset consisting of 32 SLCs (Track 480, Frame 2673), acquired between December 2004 and January 2009. PS displacement mean rate maps are draped over the geomorphological map of the study area, located in the western flank of Lake Como (nearly 15 km2, Northern Italy). The average Line of Sight (LOS) velocity has been saturated at ±10 mm/yr for visualisation purposes.

Table 1. COSMO-SkyMED dataset. A stack of 12 SCS_U HIMAGE acquisitions has been processed (Satellite: CSKS1; Look/Pass Direction: Right / Ascending; POL: HH; Beam H4-03; Incidence Angle Range: 27.73°÷31.00°; Pulse Repetition Frequency: 3.06 kHz); in bold the master selected for the interferograms. Temporal (B_t) and normal (B_n) baselines, as well as heights of ambiguity (H_a) refer to the interferograms obtained by combining the master image with the corresponding slave one.

Acquisition Date (dd-mm-yyyy)	B_n (m)	B_t (days)	H_a (m)	f_{dc} (Hz)
18-08-2008	-540.5	-176	10.1	-426.8
03-09-2008	-55.9	-160	94.7	-542.6
19-09-2008	-168.8	-144	32.3	-615.7
21-10-2008	-811.0	-112	6.7	-578.4
06-11-2008	-443.8	-96	12.3	-468.2
09-01-2009	-38.8	-32	140.2	-532.7
25-01-2009	783.3	-16	-6.9	-530.8
10-02-2009	**0**	**0**	∞	**-552.4**
26-02-2009	-531.0	16	10.3	-528.9
14-03-2009	-519.7	32	10.5	-529.1
30-03-2009	59.1	48	-92.2	-556.8
18-06-2009	59.3	128	-91.7	-570.0

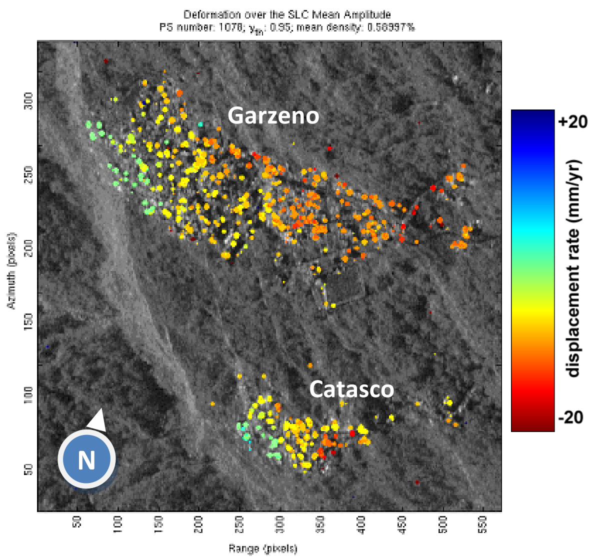

Figure 6. Case study: Garzeno - Catasco (CO). Preliminary X-band displacement rate map estimated in mm/yr over Catasco (top) and Garzeno (bottom). A dataset of 12 CSK ascending stripmap SLCs, acquired between August 2008 and June 2009, has been processed by SPINUA algorithm. PS are drawn over the incoherent mean amplitude of the SAR images. Displacement rates, measured along the CSK ascending LOS, increase from negligible values up to 1÷1.5 cm/yr when moving from the western to the eastern part of the villages.

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