X-band COSMO-SkyMed and C-band Sentinel missions for hazard mapping: the 2016-2017 Central Italy seismic sequence

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Abstract
In this work we exploit multi-band COSMO-SkyMed and Sentinel-1 missions through the use of Interferometric Synthetic Aperture Radar (InSAR) techniques to detect local and secondary deformation phenomena induced by earthquakes. Experimental results are here presented for the seismic sequence occurred in Central Italy on 2016-2017. The comparative analysis between X- and C-band InSAR outcomes revealed surface deformation phenomena of ~2-3cm likely ascribed to landslides and secondary faults activated by the seismic events.

Introduction

The capability of Interferometric Synthetic Aperture Radar (InSAR) measurements in constraining seismic-induced deformation has been widely demonstrated in literature by considering both large-scale earthquakes [1-2] and smaller scale events [3-4]. Nowadays, SAR systems operating at different frequencies are included in Earth Observation (EO) programs of several space agencies for risk mitigation purposes, such as the C-band Sentinel-1 (S1) mission from the European Space Agency (ESA) and the X-band Cosmo-SkyMed (CSK) mission of the Italian Space Agency (ASI).
In this paper, X-band COSMO-SkyMed and C-band Sentinel-1 InSAR data are used and compared to retrieve local seismic-induced deformations related to the seismic sequence that hit Central Italy from August 2016 to January 2017. Indeed, besides large co-seismic deformations, this long seismic sequence further induced several local deformation phenomena, such as landslides or avalanches, which may further impact the interested areas providing non-negligible losses in terms of human life, building damages and environmental instabilities. As a result, an effective monitoring strategy is recommended to detect and monitor such phenomena at local scales for risk mitigation purposes.
Experimental results have been gathered over the test area of Mount Sibillini, where COSMO-SkyMed and Sentinel-1 SAR data have been processed through InSAR techniques. The comparison between X- and C-band InSAR products revealed displacement fields on the order of few centimetres, which were most likely associated to landslide phenomena. The crosschecking between multi-platform InSAR products allowed enhancing the benefits and constraints of multi-band SAR missions for observing small- and large-scale displacement fields with different resolutions and accuracies.

1. 2016-2017 Central Italy Seismic sequence: settings, data and processing

The 2016-2017 Central Italy seismic sequence consisted of more than 60 earthquakes with magnitudes greater than Mw 4.0 spanning from August 2016 to January 2017. The sequence was interested by 4 mainshocks characterized by a normal fault mechanism and located among Marche, Umbria and Abruzzo regions (http://cnt.rm.ingv.it/). The first events, a Mw 6.0 earthquake, occurred on August 24th 2016 close to Amatrice village. It was followed by a Mw 5.9 earthquake, located in Visso village, that occurred on October 26th 2016. Afterwards, a stronger Mw 6.5 earthquake struck the area surrounding Norcia on October 30th 2016. Finally, another Mw 5.5 earthquake occurred on January 18th 2017 near Montereale town. Many foreshocks and aftershocks (with Mw even greater than 5.0) were also observed during this temporal span. The four mainshocks have been located at a depth of ~10 Km in an area of ~ 70 Km of extension (http://cnt.rm.ingv.it/).

In this framework, X-band COSMO-SkyMed and C-band Sentinel-1 InSAR data were collected and processed along both ascending and descending orbits, to retrieve secondary local deformations induced by earthquakes. Sentinel-1 data were acquired in the Interferometric Wide Swath (IW) acquisition mode. The latter ensures a spatial resolution of ~3x15 m and ground coverage of about 250x250 km. COSMO-SkyMed SAR data were collected in StripMap acquisition mode, which ensures a spatial resolution of about 2x2 m and ground coverage of 40x40 km.

2. Results

We show some meaningful results relevant to the Northern Sector of the Mount Sibillini, close the town of Bolognola. COSMO-SkyMed data were acquired on October 23rd and 31st 2016 whilst Sentinel-1 SAR data were acquired on October 26th and November 1st 2017 both along the descending orbit. COSMO-SkyMed and Sentinel datasets are processed to investigate the possible effects induced by Visso and Norcia earthquakes. The latter occurred on October 26th and 30th 2016 with the respective epicenters located at ~10 Km one from each other.
Figures 1(a) and 1(b) show the 2-dimensional InSAR displacement from COSMO-SkyMed and Sentinel InSAR data, respectively. They reveal a localized displacement field that reach a maximum value of about -2.5cm, likely due to a landslide moving from NW to SE. The temporal interval covered by SAR acquisitions encompasses both the Visso and the Norcia earthquakes, hence it is not possible to discriminate which of the two events activated the landslide. However, a portion of the larger co-seismic displacement field due to the Norcia earthquake is clearly visible in the bottom left corner of Figure 2(b). Based on its greater magnitude with respect to the Visso seismic event, it is most likely that the Norcia earthquake is responsible for the observed phenomenon.
Two other meaningful results are shown in Figures 2(a) and 2(b) for the area of Monte Vettore and Podalla, respectively. They show the displacement map (in cm) obtained through the InSAR processing of X-band COSMO-SkyMed and C-band Sentinel-1 pairs, respectively. The former were acquired on August 20th and 28th 2016, whilst the latter were collected on August 21st and 27h 2016, both along the descending orbit.
CSK InSAR outcomes highlights two-deformation patterns on the Mt. Vettore flank strictly connected to the co-seismic phase of the Mw 6.0 Amatrice earthquake. The first one, visible in the bottom left corner of Figure 2(a), is due to the dislocation caused by the fault rupture on August 24th [5]. The second one, occurring along a ~5Km long continuous fracture on the flank, is likely due to the combination of tectonic and gravitational effects [6].
Finally Figure 2(b) shows the 3-dimensional (3D) view of surface displacements retrieved with Sentinel-1 data, which exhibits a maximum LoS deformation of ~2-2.5cm related to the Amatrice earthquake. Further analyses are needed to assess the outcomes imaged by the InSAR data.

3. Conclusions

In this work we used X-band COSMO-SkyMed and C-band Sentinel-1 InSAR products to detect and measure local deformation phenomena induced by the 2016-2017 seismic sequence of Central Italy.
InSAR outcomes revealed how the main seismic events of the sequence activated several landslides and secondary faults interested by deformation of ~2-3cm. On the one hand, experimental results highlighted the limits and constraints of SAR sensors to observe multi-scale deformation phenomena with different spatial resolution and coverage. On the other hand, the comparative analysis between X- and C-band InSAR results allows validating local displacement phenomena, especially when no ground truth data are available for validation purposes. Along with risk mitigation and post-earthquake intervention strategies, this information is useful for hazard assessment and rapid mapping purposes.

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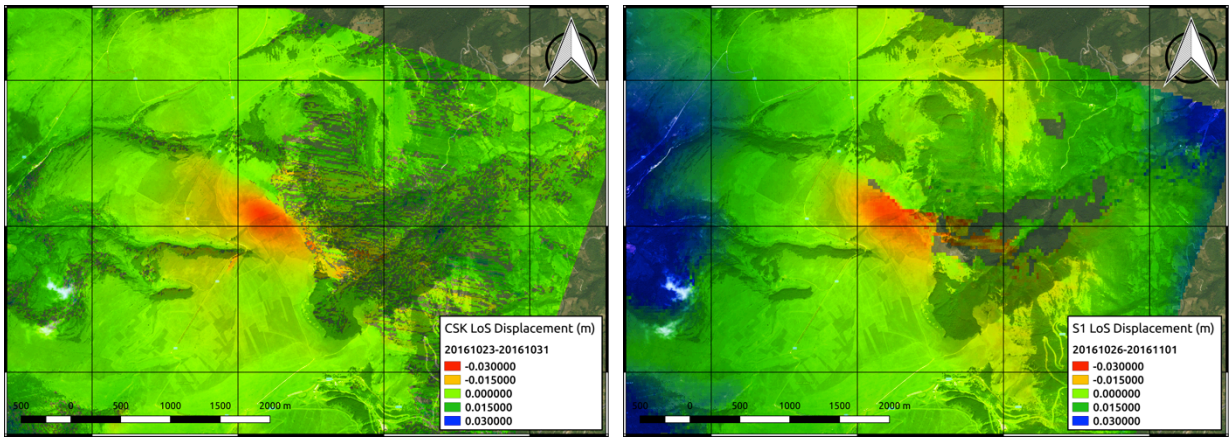
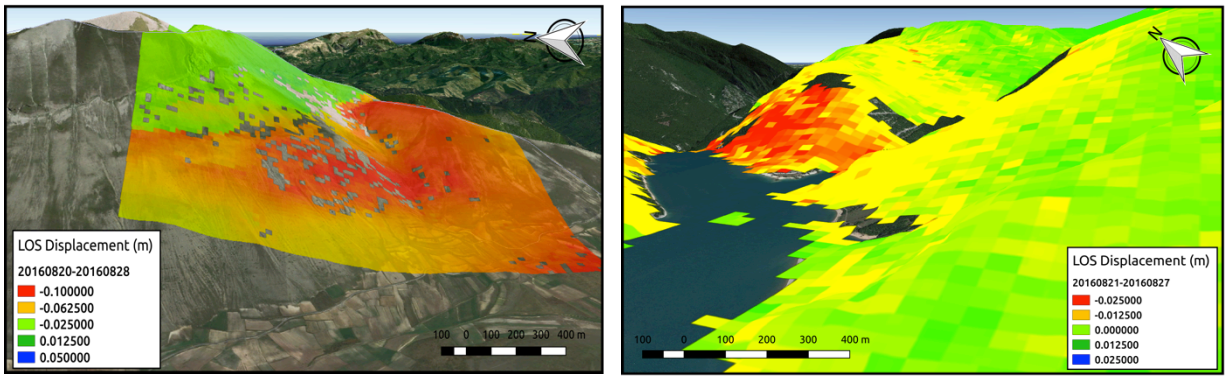


(a) *(b)*

Figure 1 – LoS Displacement field estimated with COSMO-SkyMed (a) and Sentinel (b) data.



(a) *(b)*

Figure 2 – 3D view of LoS displacement fields, estimated over Monte Vettore (a) and Podalla (b) test sites with COSMO-SkyMed and Sentinel-1 data, respectively.

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