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Ground Displacement and Building Damage Estimation of the 2017 Kermanshah Earthquake Using SAR Remote Sensing

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ABSTRACT

We used two synthetic aperture radar (SAR) datasets with different resolution to monitor the Kermanshah earthquake displacements and the buildings in Sarpole-Zahab town. We have obtained two high resolution dual-polarized (HH and HV) ALOS-2 images in strip map (SM) mode and three dual-polarized (VV and VH) Sentinel-1 images in interferometric wide (IW) mode from ascending orbits. The incidence angle of ALOS-2 and Sentinel-1 datasets were 36.2° and 38.9°, respectively. Temporal baseline of ALOS-2 dataset is 42 days, whereas pre-event and co-seismic temporal baselines of Sentinel-1 dataset are 13 and 18 days, respectively. Human activities after disasters increase and deteriorate the damage proxy maps which sometimes make the damage proxy maps meaningless. Thus, we need post-event images with shortest gaps with the event. Since the revisit cycle of ALOS-2 is rather large, we only use two ALOS-2 images to calculate ground displacement

Keywords:

SAR remote sensing, Kermanshah earthquake, Damage detection.

1. Introduction

Iran is located in a seismically active region between two tectonic plates in north and south. In the recent decades Iran experienced deadliest earthquakes with considerable casualties. For instance, in December 2003, the Bam earthquake devastated city of Bam (M 6.3) in central Iran and about 40000 people were died. Following double-earthquake of Ahar-Varzaghan (M 6.3 and 6.4) in August 2012 struck NW Iran with more than 300 deaths in remote rural areas (Karimzadeh el al., 2014) [1]. Since 2003, not only thousands were killed by earthquakes in different parts of Iranian plateau, but also more than 100000 people were displaced. On the 12th November, an earthquake with magnitude of 7.3 struck west of Iran at 21:48 Iran Standard Time (Solaymani Azad et al., 2017 [2]; Karimzadeh et al., 2018 [3]). It was the deadliest earthquake in 2017 with more than 600 casualties, 7000 injured people and 15000 homeless. According to the Iranian Seismological Network (ISN), the earthquake happened in Iranian territory in Kermanshah province, near the Iraqi border. However, the United States Geological Survey (USGS) reported earthquake in Iraq. The event was named Kermanshah or Sarpole-Zahab earthquake in Iran, and in Iraq, it was called Halabja earthquake. In this paper, we study different aspects of this earthquake and produce change proxy maps (CPMs) both from coherence and intensity methods for city of Sarpole-Zahab which heavily damaged by the earthquake.

2. The Earthquake and SAR Data

As shown in Figure 1, in the study area, there are numerous faults in Zagros thrust belt, but the source fault for the event was unknown Time (Solaymani Azad et al., 2017 [2]; Karimzadeh et al., 2018 [3]). The southern plates (Arabian plate) has a northward movement of 22 mm/yr due to recent GPS measurements (Jackson 1992 [4]). This is the main reason that the earthquakes are inevitable part of Iran especially shallow earthquakes in south-to-west parts of Iran where the epicenter of the recent Iran-Iraq earthquake is located. Focal mechanism of USGS indicates rupture occurred on a fault dipping shallowly to the east-northeast, or on a fault dipping steeply to the southwest. The previous events recorded in the Zagros thrust belt were almost shallow earthquake, and the reported depth by USGS was 19 km which indicates a shallow event. Figure 1 shows that more than 20 cities and more than 1000 villages in Kermanshah province were affected by the earthquake. The main part of structural damages were reported in early hours after the earthquake from Sarpole-Zahab, Qasre-Shirin, Salase-Babajani and Gilane-gharb by visual inspection of experts and reports of local people. But unfortunately the situation of most of the villages in the mountainous area were unknown. The earthquake was felt not only in the neighborhood provinces in Iran, but also were recorded by seismological stations in neighborhood countries such as Iraq, Turkey and Azerbaijan (Karimzadeh et al., 2018 [3]).

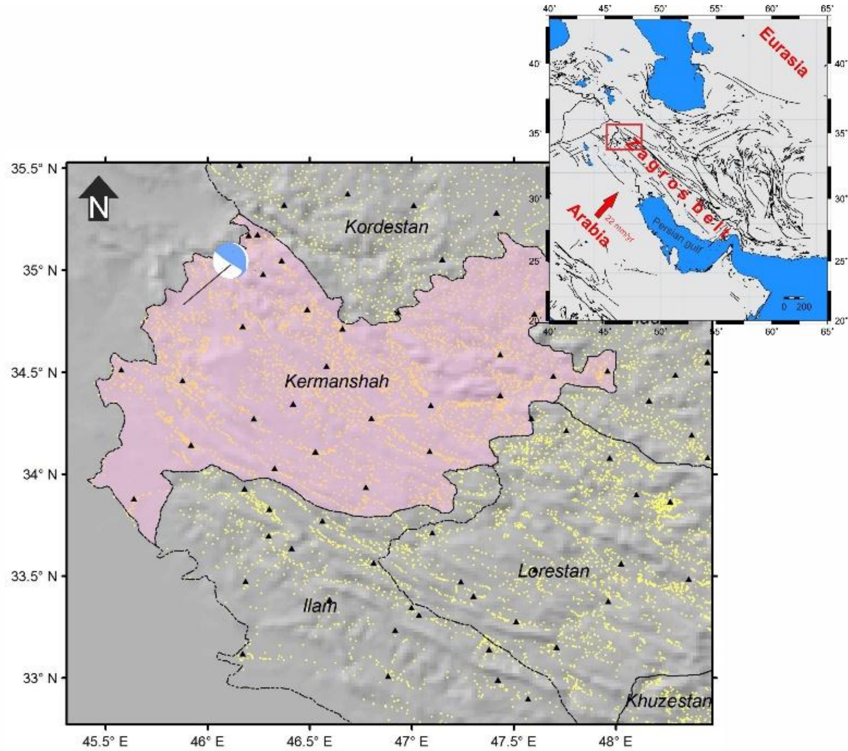

Figure 1. Inset: Fault map of Iran; Main map: location of the earthquake (November 12, 2017) and distribution of the cities (back triangles) and villages (yellow dots). Pink polygon illustrates Kermanshah province of Iran.

Since the earthquake happened in night-time, the disaster response was not fast enough and rescue teams had to wait for sunrise to conduct research in the affected areas. SAR imagery with concept of rapid disaster response is developing recently by newly launched satellites such as Sentinel-1. It has almost three times shorter repeat cycle than the former missions of European Space Agency (i.e. ERS1/2 and ENVISAT) and if Sentinel-1A and Sentinel-1B are both collecting data, the repeat cycle can be reduced to 6 days. As such, near-real-time damage monitoring is possible due to shortened revisited interval of SAR missions. Here, we used two datasets with different resolution to first monitor the earthquake displacements and then the collapsed buildings in Sarpole-Zahab. We have obtained two high resolution dual-polarized (HH and HV) ALOS-2 images in stripmap (SM) mode and three dual-polarized (VV and VH) Sentinel-1 images in interferometric wide (IW) mode from ascending orbits. The incidence angle of ALOS-2 and Sentinel-1 datasets were 36.2 and 38.9, respectively. Temporal baseline of ALOS-2 dataset is 42 days, whereas pre-event and co-seismic temporal baselines of Sentinel-1 dataset are 13 and 18 days, respectively. Human activities after disasters increase and deteriorate the damage proxy maps which sometimes make the damage proxy maps meaningless. Thus, we need post-event images with shortest gaps with the event. Since the revisit cycle of ALOS-2 is rather large, we only use two ALOS-2 images to calculate ground displacement; proxy maps were calculated from Sentinel-1 dataset.

3. Ground Displacement and Modelling

We calculated ground displacement map of the earthquake using Interferometric Synthetic Aperture Radar (InSAR) method for two ALOS-2 images (2017/10/12 and 2017/11/23) with spatial resolution of 10 m and two Sentinel-1 images (2017/10/30 and 2017/11/17). The InSAR results show about 85 cm movements in south west of the fault in the line-of-sight (LOS) of the satellite (Figure 2a), also indicate major triggered slips such as landslides in the ground surface, where two SAR signals cannot interfere with each other and looks like “sprayed sands”. Surficial movements related with the earthquake are observed in both interferograms, but the main rupture probably happened at depth (Figure 2).

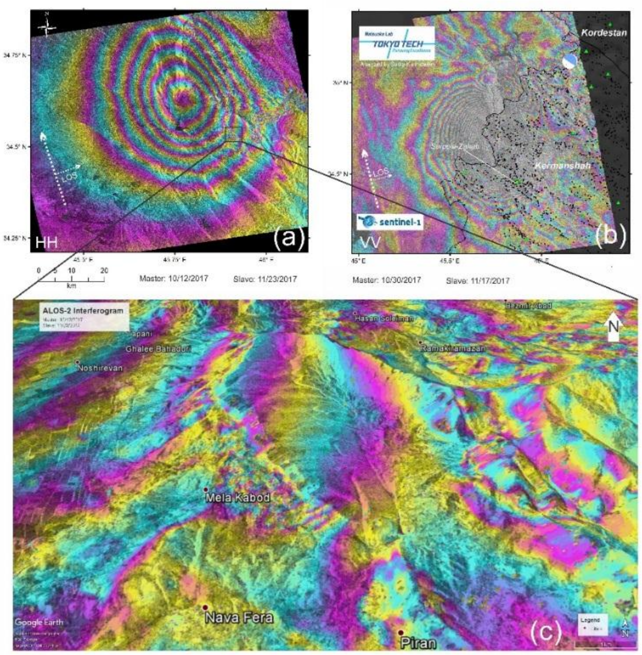

Figure 2. (a) and (b) Wrapped interferforgrams of ALOS-2 and Sentinel-1 in HH and VV polarization, respectively; each fringe shows 12 cm and 3 cm displacement in ALOS-2 interferogram and Sentinel-1 interferogram, respectively. (c) Location of the Mela Kabod landslide and its phase changes.

We applied a forward model on the ALOS-2 unwrapped interferogram to generate geocoded or slant range surface displacement maps according to tectonic movements and fault plane parameters. Because of large size of the generated displacement maps, the displacements should be down-sampled. We first applied the quadtree method to down-sample the displacement map, but the results were not satisfactory due to poor resolution of modeled displacements (Jonsson et al., 2002 [5]). We then applied a mesh from a vector file to pick up values for near-field and far-field displacements. For the near-field, we considered a dense grid size, whereas for the far-field we considered a sparse grid size. A linear inversion according to CMT fault plane parameters (strike=351, dip=10, slip=143) was applied in two steps. First we estimate the best-fit fault parameters by assuming a uniform slip and then we divide the faults into the sub-faults along strike and dip directions.

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Once the results of linear inteversion and the distributed slip over the fault is estimated, we performed a fowrad modeling by assuming the center of the fault as a reference point (Jonsson et al., 2002 [5]; Okada 1985 [6]) As shown in Figure 3, the model fits the displacements rationally well, and residuals probably indicate non-tectonic movements such as triggered landslides and land subsidence in eastern part of the study area. Figure 3c and d also show two profiles, parallel to LOS and comparison of modeled and observed displacements.

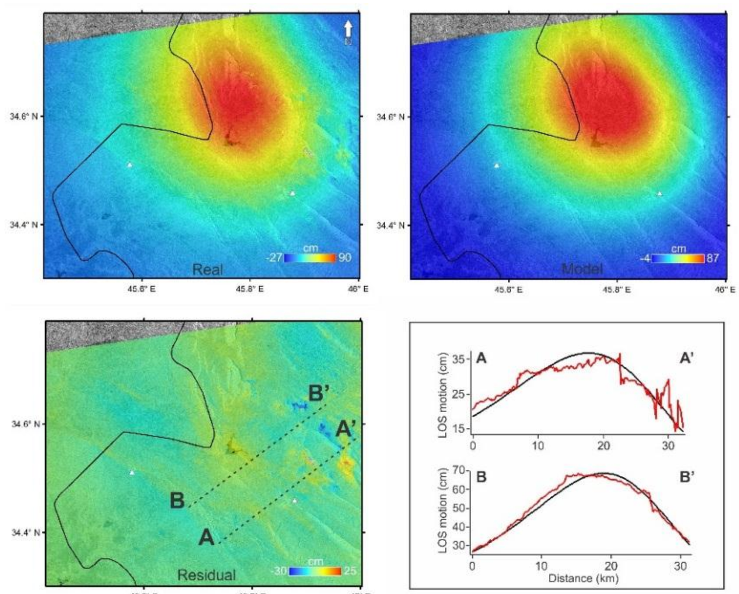

Figure 3. (a) Coseismic displacements of the 12 November 2017 earthquake; (b) modeled displacements; (c) residual map which is the difference between (a) and (b); (d) LOS profiles of the real displacements (red) and model displacements (back).

4. Change Proxy Maps (CMP)

Here, we used backscattering coefficient and phase correlation (coherence) as two indices for change mapping over city of Sarpole-Zahab. As mentioned, due to larger latency of ALOS-2 data, in this section only multitemporal CMPs from Sentinel-1 dataset were calculated. Due to complex behavior of the backscattering coefficient, the building classification was not reliable. Thus, we used RGB visualization of differential backscattering values of pre- (2017/10/30) and post-event (2017/11/17) to produce CMP of human activities during and after the earthquake such as establishment of tents, camps and debris removing. As shown in Figure 4, overall, visual comparison of the RGB results are in good agreement with the location of temporary settlements deduced from optical imagery of the United Nations Institute for Training and Research (UNITAR). We drew three profiles in SE-NW direction in Sarpole-Zahab. Red band of the three profiles indicate that the location of the large camps or temporary settlements can be detected by differential backscattering value of the pre- and post-event images.

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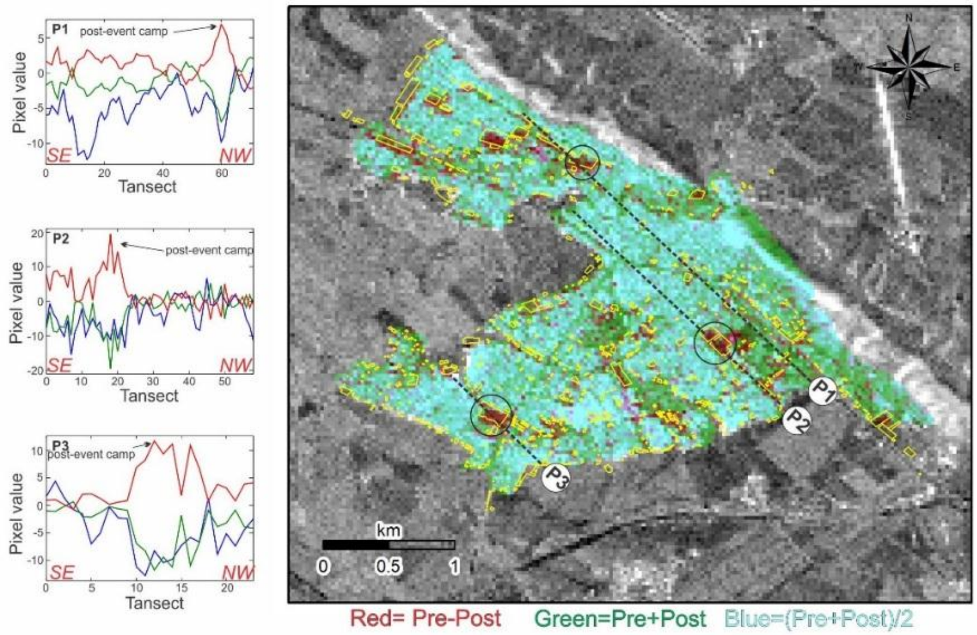

Figure 4. RGB map of scattered energy of radar from multitemporal Sentinel-1 dataset and three profiles along the Sarpole-Zahab city. Yellow polygons show the location of the temporary settlement and tents.

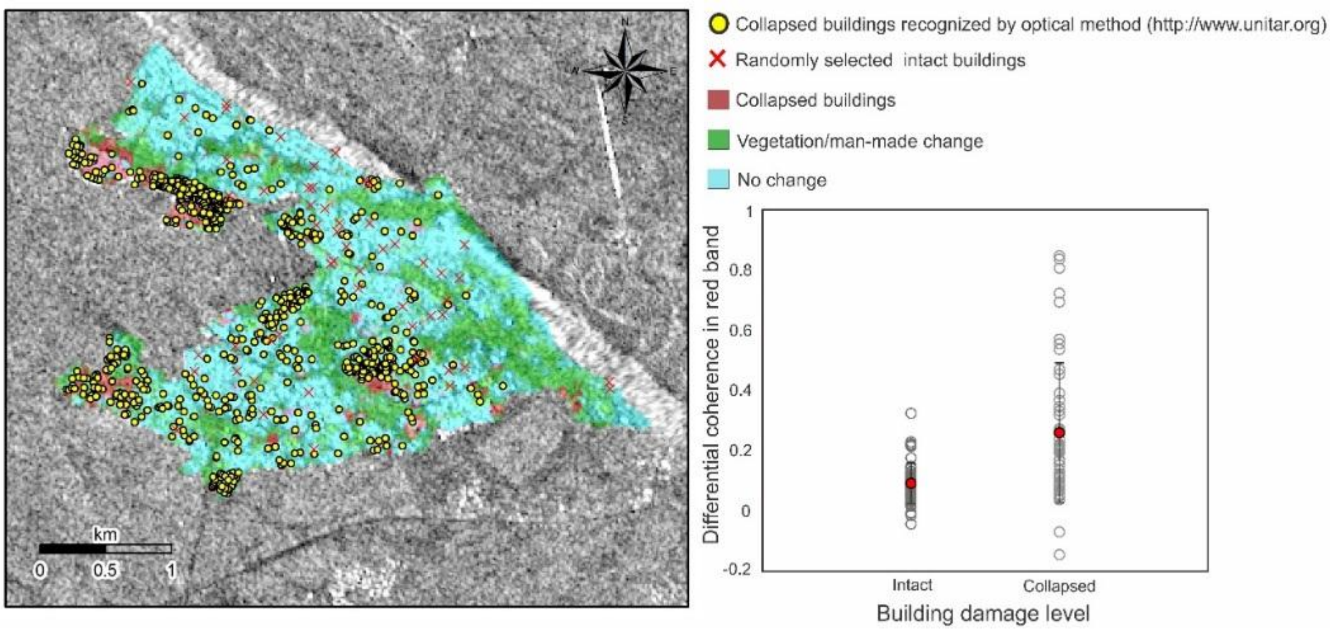

Figure 5. Left: RGB change map of Sarpole-Zahab together with collapsed buildings from UNITAR evaluation. Right: Differential coherence values (gray circles) between 50 randomly selected collapsed buildings and 50 randomly selected intact buildings over Sarpole-zahab. Red circles are mean values of each category and black bars are standard deviations.

By combining RGB visualization and coherence values, we provided a CPM of buildings in Sarpole-Zahab. We applied a methodology based on a normalized RGB color composition for the produced InSAR phase correlation maps (coherence), in which subtraction of pre-event and co-seismic coherence represents the red band, subtraction of co-seismic and pre-event coherence represents the green band and the mean coherence value of pre-event and post-event images are in blue band. Figure 5 shows that majority of buildings in three parts of the town were severely damaged. Majority of new government-built buildings are located in NW Sarpole-Zahab. These buildings are almost new, but due to non-engineered walls they were not able to resist against the severe seismic activity. On the other hand, the site condition was soft due to replacement of refilled soil after Iran-Iraq war. In central and SW parts of the town, the main reason of severe damage is type of buildings that the buildings were almost old and the material used in these houses were mainly stone and brick. Second reason is the proximity of these buildings to the agricultural lands which are formed by soft soil as well. Since the building inventory of the town was not available, we validated the results of building condition with a damage map create by optical imagery by UNITAR (http://www.unitar.org [7]). As shown in Figure 3, based on optical images, more than 600 individual buildings (yellow circles) are damaged in the town. In order to do a fair validation between SAR and optical results, we chose randomly 50 collapsed and intact buildings and calculated their multitemporal differential coherence and relative standard deviations. The results show that differential coherence value from red band is higher among collapsed buildings (Figure 5).

5. Conclusions and Discussions

SAR imagery has a good capability for near-real-time disaster response because of its limitless advantages during night and bad weather conditions when snow and could shroud optical records. RGB visualization technique together with differential coherence and backscattering values are able to detect both structural and human-related changes during and after the earthquake. However, due to coarser resolution of the Sentinel-1 data (> 20 m), detection of the collapsed buildings in small buildings was not quite successful.

6. References

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