Mapping Secondary Surface Deformation Related to the 2018 Sulawesi Earthquake via Synthetic Aperture Radar Offset Tracking

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KEY WORDS: Synthetic Aperture Radar (SAR); multi-kernel offset method; three-dimensional deformation; liquefaction; the 2018 Sulawesi earthquake.

ABSTRACT: Synthetic aperture radar (SAR) multiple kernel offset tracking provide efficient measurements of large and complex surface deformations, which is approximately three times more accurate than traditional offset tracking approaches. This method allows measurement of precise two-dimensional (2D) surface deformations from a pair of interferometers through azimuth and slope offset measurements, resulting in precise three-dimensional (3D) surface deformations from ascending and descending interferometer pairs. It is very important to measure precise 3D deformations because 3D deformation measurements are allowed to improve understanding of geological events such as earthquakes, volcanic eruptions, and glacier movements. The 2018 Sulawesi earthquake is M 7.5, which occurred on September 28, 2018. Because of fault movement, the surface deformation of about -3.5, 3.7 and -2.5 m in the east, north and upper direction occurred, respectively. In addition, there also were reports of secondary surface deformation such as landslides, liquefaction and land subsidence. Secondary surface deformation extremely increased the damage caused by the earthquake. However, the measuring surface deformation was only focused on the fault movements. In this study, we proposed a deformation field related to the Sulawesi earthquake by integrating multiple kernel-based offset tracking measurements in ascending and descending interferometer pairs of space-based SAR sensors. Especially we focus on secondary surface deformation. For that, we utilized two ALOS-2 PALSAR-2.

1. Introduction

The 2018 Sulawesi earthquake was deadliest earthquake in 2018 (USGS, 2018). Moreover soil liquefactions and landslides caused by the earthquake destroy many buildings and cause another hundreds of deaths or missing (USGS, 2018). The earthquake triggered left-lateral strike slip fault in near north-south direction. Because of large earthquake, a large amount of surface deformation, up to 6 to 8 m occurred extends over 100 km(USGS, 2018).

Synthetic aperture radar (SAR) based multi-kernel offset tracking enable us to observe large and complex displacements without unwrapping error (Martinez-Espla et al., 2008; Baek et al., 2018; Chae et al., 2017). Offset tracking method generates intensity-cross correlation in such size of kernel window between master and slave Single Look Complex (SLC). And offset tracking directly measure the distance of the peak between two SLCs (Strozzi et al., 2002). So large and complex surface deformation could be easily measured. Besides, by using offset tracking, the Line-of-Sight and along track deformation could coincidently be measured since the distance between the peaks were directly measured (Baek et al., 2018; Chae et al., 2017).

Furthermore, three-dimensional surface deformation could be retrieved by integrating offset maps from ascending and descending pairs. SAR-based three-dimensional mapping is very helpful tool to understand large-area fault mechanism and following secondary surface deformation. In this study, we mapped surface displacements caused by the 2018 Sulawesi Earthquakes in three-dimension. Especially we focused on the secondary surface deformation such as liquefaction and landslides. For that we employed multi kernel based offset tracking approach to measure large and complex surface deformation. ALOS-2 PALSAR-2 co-seismic pairs from ascending and

descending orbits were utilized.

2. Study area and Data

In Sulawesi, Indonesia, Mw 7.5 of earthquake occurred at 28th September 2018. The triggered fault showed left-lateral strike slip faults extending over 100 km in direction of near north-south. As a result, near the fault zone maximally more than horizontal deformation of 6m were observed in in-situ measurements (USGS, 2018).

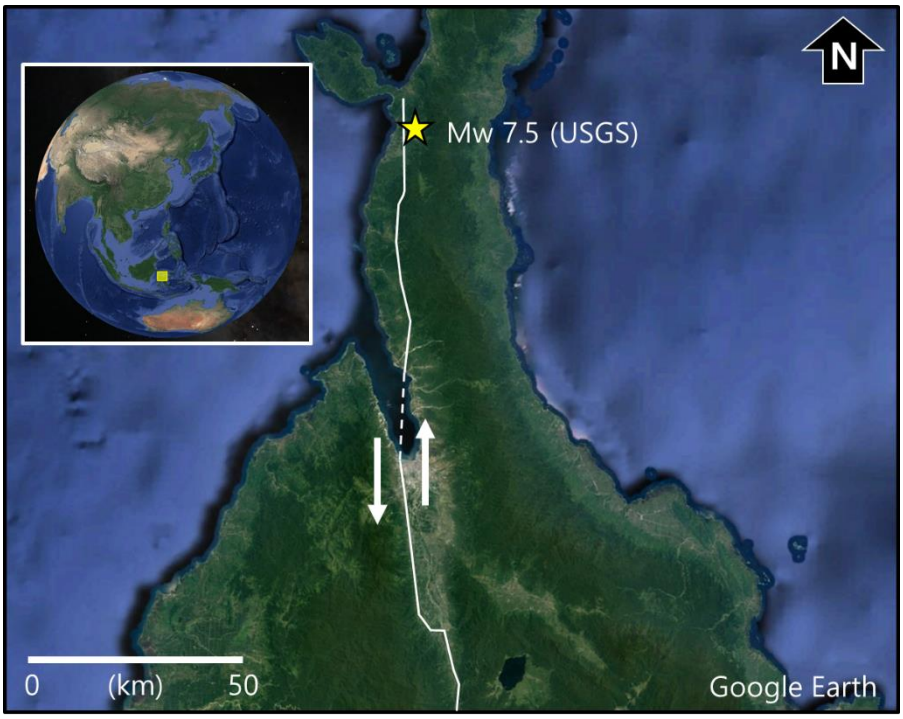

Figure 1. The study area; 2018 Sulawesi earthquakes; The satellite imagery acquired from Google Earth; White solid line indicates fault lines; Yellow star illustrates the location of main shock; and white arrows indicate the moving direction of faults.

ALOS PALSAR2 interferometric pairs used are listed in Table 1. Temporal and perpendicular baseline of an ascending pair were longer than them of a descending pair. The pixel spacing of ground range and azimuth directions were about twice and 5 times different in an ascending and a descending pair respectively. The measurement accuracy of offset measurement largely depend on the resolution. Therefore it is expected that measurements accuracy of range offset maps were lower than them of azimuth offset maps.

As the deformation area were too large to measure with only one scene of pairs. So we concatenated four Stripmap SLCs. And two swath of ScanSAR data were used. In case of a descending pair, measurements jump between the swaths could be observed because each swath data separately processed.

Table 2. Principal Parameters of interferometric pairs

Parameters	ascending	descending
Acquisition date (YYMMDD)	180817_181012	180927_181011
Acquisition Mode	Stripmap (SM3)	ScanSAR (WD1)
Temporal baseline(days)	56	14
Perpendicular baseline (m)	340	-120
Incidence angle (Deg.)	31.45	39~43
Ground range pixel spacing (m)	11.56	~13
Azimuth pixel spacing (m)	5.6	2.89

3. Methodology

3.1 Multi kernel offset

Deciding optimal kernel size is very important to utilize traditional offset tracking approach, but also is time consuming. Recently some study suggested multi-kernel based offset tracking approach (Chae et al., 2017; Rott et al., 1998). In this approach, the representative deformation was calculated for the offset map with different noise characteristics according to different kernel sizes. In the process of three-dimensional median and average filtering the noise signal is suppressed. Therefore, the resolution is well maintained with better precision. Detailed processing steps of multi-kernel based offset tracking is as below.

(1) Common-band filtering for master and slave SLC
(2) Co-registration between two SLC
(3) Multiple offset map generation using various size of kernels
(4) Three-dimensional median filtering

More detailed data process of multi-kernel based offset tracking was written in (Baek et al., 2018; Chae et al., 2017)

3.2 3D mapping

Finally we retrieved three-dimensional surface deformation by integrating range offset maps of ascending and descending pairs and azimuth offset map from multi-kernel based offset map (Jung et al., 2011; Jo et al., 2017). The equation as below showed calculating three-dimensional surface deformations d) where unit (x, y, z) vector u), weight matrix ($\sum$) and azimuth and range displacements (r) (Hu et al., 2014; Jung et al., 2011; Jo et al., 2017).

$$\hat{d} = -(\hat{u}^T \Sigma^{-1} \hat{u})^{-1} (\hat{u}^T \Sigma^{-1} \hat{r})$$ formulation. 1

4. Results

Figure 3 shows three-dimensional surface deformation retrieved from range and azimuth offset maps from both ALOS PALSAR-2 ascending and descending orbit. In the north-south deformation map (Fig. 3b) the clear left-lateral strike-slip deformation pattern could be recognized. However in case of east-west (Fig. 3a) and up-down(Fig. 3c) directional measurements, the severe noise pattern lower the recognizability. The low qualities of these two measurements resulted from the descending range offset map. So in further study, I plan to enhance the measurements precisions of the descending range offset map.

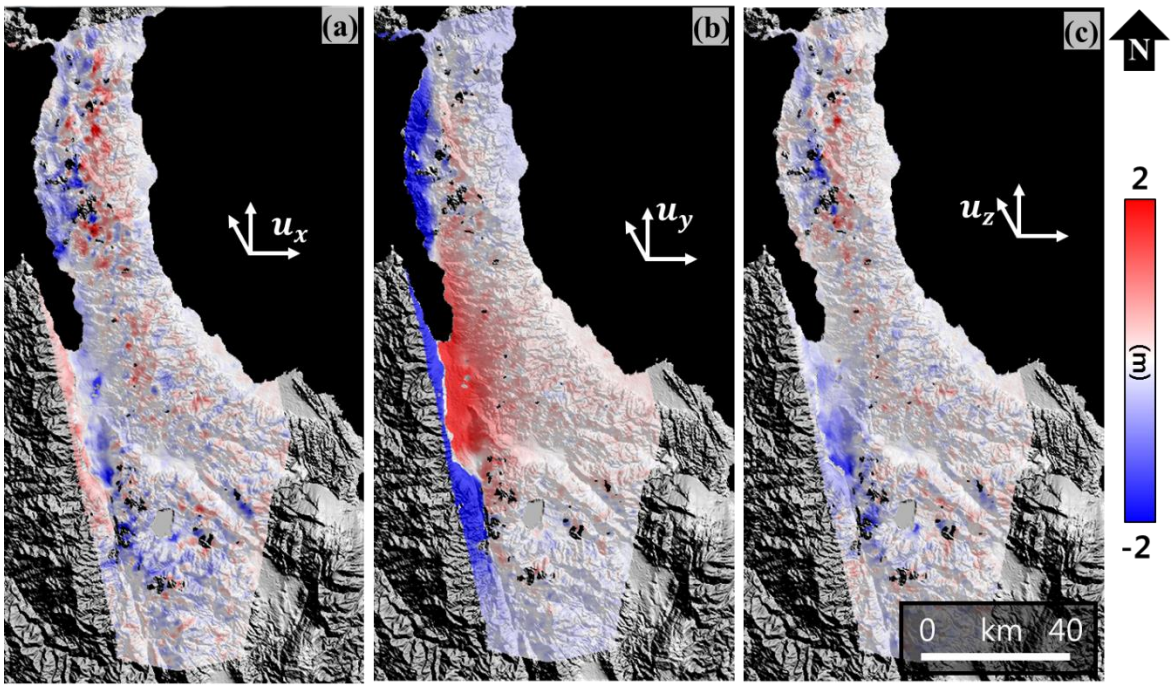

Figure 2. Three-dimensional deformation measurements from SAR offset maps; (a) east-west; (b) north-south; (c) up-down

5. Summary

In this study, we suggested preliminary results of three-dimensional deformation mapping related to 2018 Sulawesi earthquake. As the results, the deformation pattern of left-lateral strike-slip faults was clearly recognized in near north-south direction. However because of the descending range offset map which show low quality, the measurement precision of retrieved east-west and up-down deformation also lowered. And we plan to improve the descending range offset map in order to enhance the three-dimensional measurement precisions.

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