SURFACE CHANGE OF THE 6TH NUCLEAR TEST OF NORTH KOREA ON 3 SEPTEMBER 2017 DETECTED BY USING SAR IMAGES

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ABSTRACT

We analyzed ALOS-2 and TerraSAR-X SAR images to interpret and qualify the tendency of the displacement caused by the 6th Nuclear Test of North Korea at Mt. Mantap. 3-D true displacement vectors around the rim of the explosion were obtained by using three interferograms from different tracks of ALOS-2. It indicates a uniform explosive tendency of up to 25cm in the east to west direction. The movement of the ruptured zone where interferometric coherence is completely lost was detected by visual inspection and offset tracking technique using two pairs of TerraSAR-X images acquired in descending and ascending orbits. The major tendency of the motion on slopes covered with vegetation was mostly towards the direction of gravity. However, many stable features that haven't moved at all were observed corresponding to outcrops and bedrock. It implies that the motion of displacements was mostly the landslides of the topsoil and boulder stones.

Index Terms— Nuclear Test, Surface Displacements, InSAR, Visual Inspection, Offset Tracking

1. INTRODUCTION

The 6th nuclear test was conducted in Punggye-ri, North Korea on 3 September 2017 that was equivalent to 6.1mb. Wang *et al*. (Science, 2018) performed 3-D surface displacements analysis using offset tracking technique. Moreover, they made a source model in comparison with the result of surface displacements. They assumed that the bedrock of Mt. Mantap is the uniform elastic medium and followed the scenario of elastic explosion(expansion), collapse, and compaction. However, they clarified that there may be problems in the model if the bedrock has a non-uniform structure and surficial processes such as landslides [1].

On the contrary, we observed asymmetric motions and many stable features that did not move at all on the mountain slopes as the evidence of landslides obtained from sets of SAR images.

2. STUDY AREA & DATA

Mt. Mantap is located in Punggey-ri, Gilju-gun, Hamgyongbuk-do, North Korea. The location of the epicenter is estimated at 41.300°N/129.078°E ± 50m. The height of Mt. Mantap is 2205m, and the bedrock is composed of solid granite. There are volcanic sediments on the top, therefore, there may be a possibility of landslides on the surface. We divided the study area into two sections that are the ruptured zone and the rim part.

Table 1. Dataset of ALOS-2 PALSAR-2

Pairs	Date (yyyy/mm/dd)	Incidence Angle	Range Pixel Spacing	Azimuth Pixel Spacing
1 (ASC)	2017/07/27	34.08	4.29	3.96
	2017/09/07			
2 (ASC)	2017/08/29	43.47	1.43	1.94
	2017/09/12			
3 (DES)	2017/08/31	37.53	1.43	2.23
	2017/09/28			

Table 2. Dataset of TerraSAR-X

Pairs	Date (yyyy/mm/dd)	Incidence Angle	Range Pixel spacing	Azimuth Pixel Spacing
1 (ASC)	2017/06/05	33.6	0.91	0.85
	2017/09/12		0.45	0.86
2 (DES)	2017/08/24	48.3	0.45	0.86
	2017/09/04			

In this study, we used six ALOS-2 PALSAR-2 images acquired before and after the event on three different tracks and made three interferograms for detection of the movement around the rim part. Moreover, four UBSR images that have better spatial resolution were used for visual inspection and offset tracking. In addition, we used four TerraSAR-X images acquired before and after the event on two different tracks and performed visual inspection and offset tracking for detection of displacements on the ruptured zone.

3. DATA PROCESSING

3.1. InSAR Processing

Three-dimensional displacements were acquired through InSAR processes as shown in Figure 1 below. LOS displacements were obtained from the unwrapped phase after DInSAR process. The atmospheric effect was reduced by using the statistical correction assuming that the atmosphere is horizontally homogeneous. We determined the absolute displacements by setting the value of the displacement to zero where surface changes did not occur.

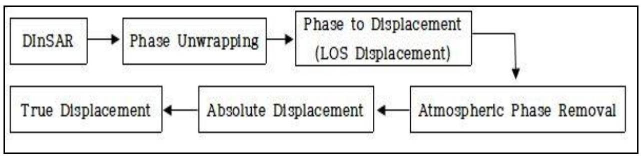

Figure 1. Flowchart of InSAR processes.

3 by 3 LOS unit matrix was composed by using values of the incidence angle and the satellite heading from three interferograms.

$$\mathbf{d}=\mathbf{L}\cdot\mathbf{s}$$

(**d**: A displacement vector with three DInSAR displacements in LOS directions, **L**: LOS matrix composed of three LOS row vectors, **s**: 3-D displacement vector)

The 3-D true displacements were extracted by following the computation below.

$$\mathbf{s}=\mathbf{L}^{-1}\cdot d$$

3.2. Visual Inspection & Offset Tracking

Visual inspection and offset tracking were performed through a series of processes as shown in Figure 2 below. SAR images of the slant range were converted into the ground range images. In sequence, we visually compared two images acquired before and after the event and applied offset tracking technique to detect surface changes at the ruptured zone. Results were projected on Google Earth domain after the terrain correction.

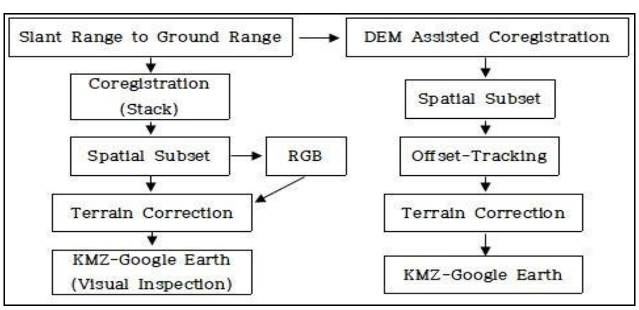

Figure 2. Flowchart of visual inspection & offset tracking.

4. RESULTS

Figure 3 shows E-W true displacement obtained by InSAR processes. Displacements of 5 to 25cm and 9 to 25cm were observed on the east slope and the west slope each. On the south-southeast slope where the portal is located, the displacement of 6 to 9cm was detected.

The south-southeast slope is presented in Figure 4 and 5. As comparing between before and after images, there is a general pattern towards the direction of gravity. However, there are large numbers of stable features in the middle of the general pattern as point, line, and plane shape marked with a red circle. Especially, the boundaries of these features haven't moved at all in Figure 5.

A result of offset tracking that obtained by setting registration parameters such as window size and maximum velocity reflects the aspect of visual inspection in Figure 6. There are displacements of 3 to 3.5m on the west-southwest slope and 2 to 2.5m on the east slope.

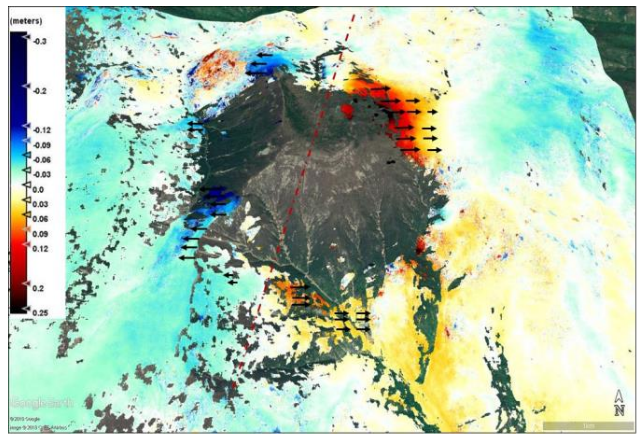

Figure 3. E-W true displacement from InSAR processes.

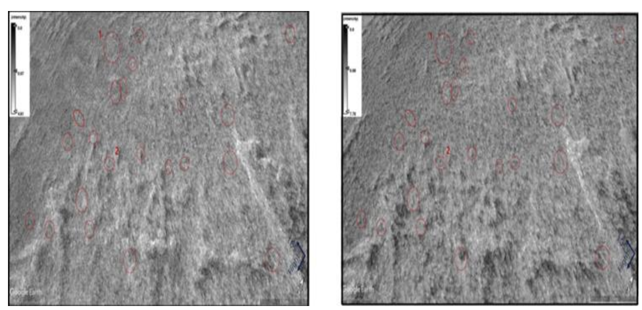

Figure 4. Terrain corrected images of TerraSAR-X descending pair. (Left) 0824, (Right) 0904.

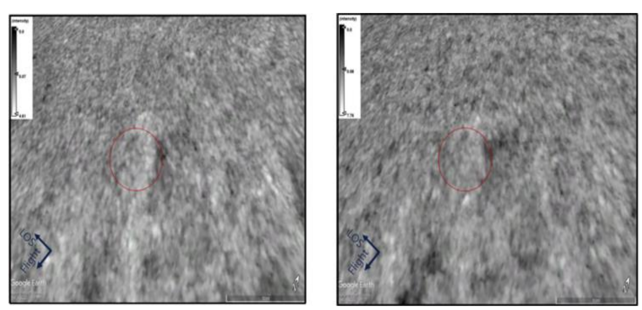

Figure 5. Enlarged terrain corrected images of point 1 in figure 4. (Left) 0824, (Right) 0904.

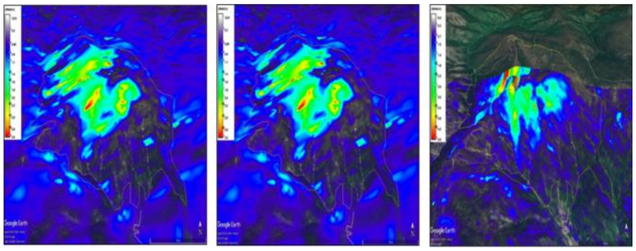

Figure 6. Displacement from offset-tracking. (Left) 0829-0912 ALOS-2 Ascending, (Center) 0831-0928 ALOS-2 Descending, (Right) 0824-0904 TerraSAR-X Descending.

5. CONCLUSIONS

We verified the surface displacements caused by the 6th nuclear test using InSAR, visual inspection and offset tracking. All points must present motion if entire bedrock had undergone expansion and compaction. However, we confirmed that there are many fixed outcrops among displacements flowing in the direction of gravity. Moreover, displacements are locally concentrated on the southwest-southeast slope and unevenly distributed. The displacement at the ruptured zone is considered as landslides of unconsolidated soil, thus the source model of Wang *et al*. (2018) might have errors in the depth of the hypocenter and the scenario.

6. ACKNOWLEDGMENT

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7. REFERENCES

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