A TIME-SERIES OF LAND SUBSIDENCE IN BUSAN, KOREA WITH ALOS PALSAR MULTI-TEMPORAL OBSERVATIONS

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ABSTRACT: Land subsidence is a gradual or sudden downward sinking due to mainly large amounts of groundwater extraction and soil compaction. Periodic monitoring of ground subsidence is important to protect invaluable lives and properties. Although terrestrial in-situ observations such as Global Positioning System (GPS) survey can provide accurate surface's displacement at a specific point with very high temporal resolution but limited spatial resolution, it has a limitation to obtain surface displacement information of wide areas. Differential radar interferometry has provided high spatial surface's deformation map with Synthetic Aperture Radar (SAR) observations. Especially a time-series of surface's deformation using the Small BAseline Subset (SBAS) approach enables us to reduce atmospheric artifact and topographic errors with multi-temporal SAR observations. In this study, the SBAS technique with L-band ALOS PALSAR observations has been utilized to monitor land subsidence in Busan, South Korea. Total 19 SAR images were acquired from 15-Sep-2007 to 24-Dec-2010 with geometric baseline from -2832 to 1855 meters. Nine points were selected to show significant subsidence signals from ALOS PALSAR time-series of ground displacement estimated by the SBAS technique. The results of time series show that average velocity rate of the largest land subsidence is -3.68 cm/year at the line of sight (LOS) direction.

1. INTRODUCTION

The land subsidence which caused by natural and anthropogenic activities such as groundwater and oil withdrawal (Amelung et al., 1999), tectonic movement (Dehls et al., 2002) and unconsolidated basement (Kim et al., 2005), can be observed around the world. Because, it often threatens our invaluable lives and properties, it is important to monitor, predict and mitigate the land subsidence. Terrestrial measurements like Global Positioning System (GPS) or leveling data can provide very reliable information on surface's displacement (Abidin et al., 2008). However, it is difficult to estimate the surface displacement with high spatial resolution at a time using only these traditional measurements in a wide range of areas, because they are cost and time-consuming. Synthetic Aperture Radar satellites which use microwave electromagnetic waves can detect Earth's surfaces in all weather conditions or even night time. It is well known that space-based differential Interferometric SAR (DInSAR) approaches shows promising results of land subsidence monitoring (Kim, 2004; Kim et al., 2005; Kim et al., 2007; Cho and Lee, 2014). Although it can be often degraded by loss of coherence from various decorrelation effects, the DInSAR technique can observe ground deformation with an accuracy of up to a portion of half of microwave wavelength being employed. Moreover, the development of advanced DInSAR techniques like Small Baseline Subset (SBAS) and the Permanent Scatterer Interferometry (PSI) (Ferretti et al., 2001; Berardino et al., 2002; Lanari et al., 2004) enable to retrieve a time-series of surface's displacement with from a few mm to cm accuracy. A several studies on subsidence in Busan area using DInSAR application have been reported (Kim, 2004; Kim et al., 2007; Cho and Lee, 2014). Kim (2004) monitored the subsidence from 1992 to 1998 with JERS-1, RADARSAT-1 and ERS-1, 2 data using PSI processing. The result shows the land subsidence had been occurred on Dukpo station, Sasang-gu, Gamjeon-dong and Bum bridge II (Kim, 2004). Kim et al. (2007) also reported about the subsidence from 1992 to 1998 with JERS-1 data using PSI processing (Kim et al., 2007). The subsidence rate in both studies is about from 24 to 30 mm/year. Cho and Lee (2014) observed subsidence using SBAS in Nok-san area which located at the southern part of Busan using RADARSAT-1 and Envisat from 2002 to 2007. The maximum subsidence rate is 10 cm/year and average rate is 6 cm/year (Cho and Lee, 2014). In this study, we would like to see the phase continuity of the ground subsidence from 2007 to 2010 using the total of 19 ALOS PALSAR dataset using SBAS technique generating a time-series displacement map showing spatiotemporal subsidence.

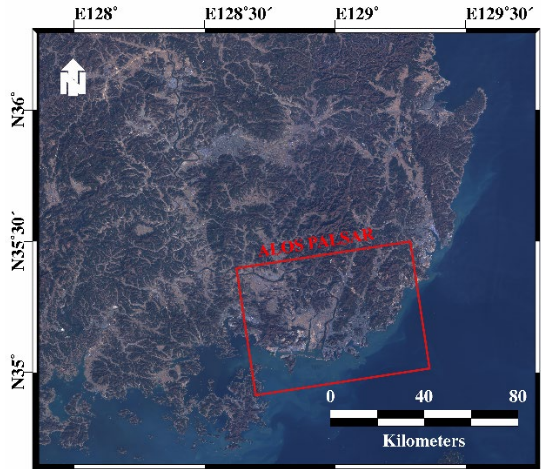

Figure 1. The Landsat-8 optic image which was acquired on 22-Jan-2019 showing study area of the Busan located at the southeastern part of the Republic of Korea (Image courtesy of USGS/NASA Landsat). The swaths of ALOS PALSAR were represented with red rectangle box.

2. METHOD

A time-series analysis using remote sensed imagery is a good approach to monitor ground subsidence plotting the trend of the surface's displacement. The Small BAseline Subset (SBAS) which proposed by Berardino et al., process the interferograms which have a small baseline among all of interferometric pairs to deal with more coherent interferometric phases (Berardino et al., 2002). Therefore, the SBAS can relieve the spatial decorrelation and possible artifacts of the interferometric phase using removing atmospheric phase screen. The SBAS algorithm also minimizes unwrapping error by using the residual phase that removes the surface displacement calculated from average velocity (Berardino et al., 2002). This algorithm uses singular value decomposition (SVD) to observe continuously the time series deformation from the temporal disconnected differential interferogram (Strang, 1988). However, the displacement phase calculated by the SBAS algorithm does not remove sufficiently phase noises (Kim, 2008). Therefore, the spatial low pass filter and the temporal high pass filter which derived from PSI approach were applied to reduce the atmospheric phase (Ferretti et al., 2001). The SBAS also can calculate the estimate of the topographic error. By stacking the more interferograms with high coherence, the SBAS can easily distinguish which phases caused by subsidence in a time-series (Berardino et al., 2002).

3. DATASET AND DATA PROCESSING

We collected total of 19 ALOS-PALSAR raw data from September 2007 to December 2010, which provided by the 4th of research agreement (RA4) from Japan Aerospace Exploration Agency (Table 1). The wavelength of ALOS-PALSAR is the L-band (23.5 cm). Interferometric coherence in longer wavelength like the L-band can be maintained compared with relatively shorter wavelength like C- or X-band (Hong et al., 2010; Kim et al., 2013; Hong and Wdowinski, 2014). Thus interferometric pairs with slightly larger perpendicular baseline can be utilized to apply the SBAS technique (Sandwell et al., 2008). The revisit cycle of the ALOS PALSAR is 46-day and its off-nadir angle is 34.3°. The flight direction of the collected ALOS PALSAR image is ascending and path number and frame number are 426 and 690, respectively. Both Fine Beam Single (FBS) with HH-pol and Fine Beam Double (FBD) with HH+HV pol have collected 13 and 6 images respectively. Because beam mode of the master image is the FBD, the FBS images should be resampled the same size as the FBD with adjusting the pixel spacing in range direction.

Table 1.
List of ALOS-PALSAR datasets used

No.	Acquisition Date	$\boldsymbol{B_{Perp}}$ [m]	$\boldsymbol{B_{Temp}}$ [days]	No.	Acquisition Date	$\boldsymbol{B_{Perp}}$ [m]	$\boldsymbol{B_{Temp}}$ [days]
1	2007-09-15	0	0	11	2009-06-20	-1128.2	644
2	2007-10-31	536.1	46	12	2009-08-05	-1602.1	690
3	2007-12-16	671.2	92	13	2009-09-20	-999.2	736
4	2008-01-31	1106.7	138	14	2009-11-05	-567.9	782
5	2008-03-17	1214.3	184	15	2009-12-21	-343.6	828
6	2008-05-02	1855.1	230	16	2010-02-05	183.5	874
7	2008-06-17	-1670	276	17	2010-05-08	650.2	966
8	2008-09-17	-2831.5	368	18	2010-08-08	1002.4	1058
9	2008-11-02	-2563.6	414	19	2010-12-24	1528.5	1196
10	2009-02-02	-1936.1	506				

The maximum perpendicular baseline is 1500 m and the maximum temporal baseline is 1500 days. The network of interferometric pair for the SBAS approach is shown in Figure 2. The color of line represents a level of average coherence. We utilized the Gamma software (Werner et al., 2000) to make single look complex data and generate interferograms. In order to generate coherent interferogram, a precise co-registration considering topographic effect has been applied. The multi-looking processing with the range for 4, azimuth for 12 were applied to reduce speckle noise in the interferograms. The Shuttle Radar Topography Mission (SRTM) DEM were used to remove the topographic phase from the interferogram (Farr et al., 2007). An adaptive filtering has been applied to improve the DInSAR image (Goldstein and Werner, 1998). Finally, each differential interferograms were unwrapped using Minimum cost flow (MCF) algorithm to obtain absolute phase (Costantini, 1998). After phase unwrapping, total of 85 differential interferogram were used for application of SBAS method with MintPy software (https://github.com/yunjunz/MintPy). The singular value decomposition (SVD) algorithm was applied to estimate the displacement velocity vector in the SBAS application. For removal of the atmospheric phase, we applied the low-pass filter in space and the high-pass filter in temporal. Through those procedures, the time series deformation is calculated.

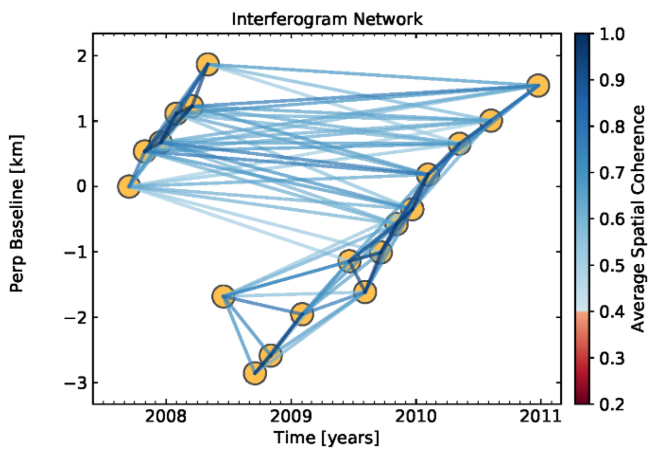

Figure 2. Interferogram network of the ALOS PALSAR. The x-axis is the temporal baseline and the y-axis indicates perpendicular baseline. The solid line is the interferometric pair with coherence level as shown color bar used for the SBAS application.

4. RESULT

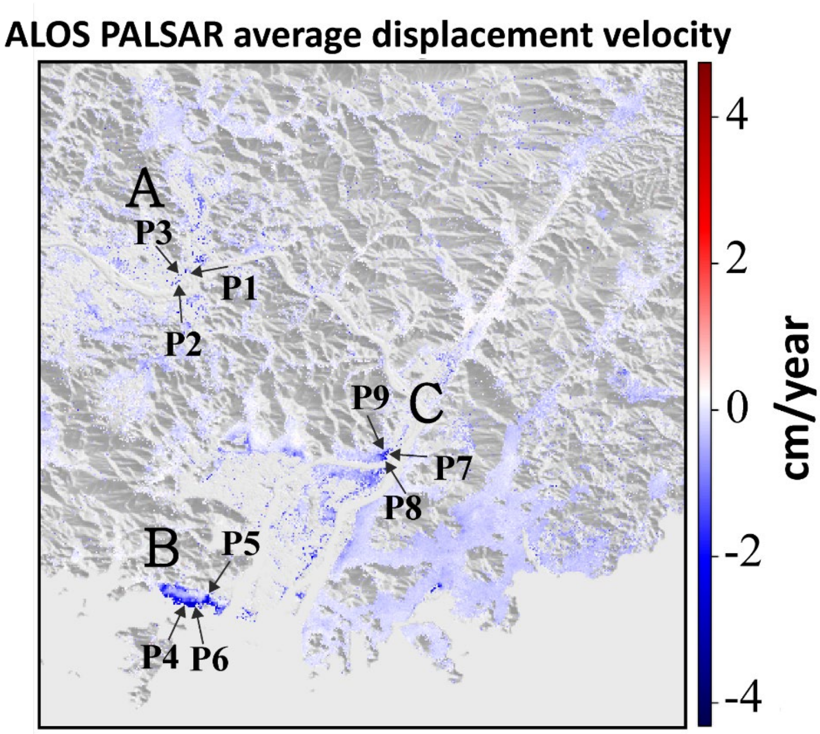

Figure 3. The average velocity map of ground displacement using ALOS PALSAR. The A shows Miryang city, B represents Nok-san reclaimed area, and C is Gimhae city. Those sites are mainly composed of sand and clay alluvial deposits which might be compacted easily (Min et al., 2002; Yang and Cho, 2011).

The result shows the significant land subsidence at A, B, and C areas as shown in Figure 3. The A shows Miryang city, B represents Nok-san reclaimed area, and C is Gimhae city. Those 3 sites are located near Nak-dong river and mainly composed of sand and clay alluvial deposits at geological aspect which might be compacted easily (Min et al., 2002; Yang and Cho, 2011). We examined the average velocity rate of significant land subsidence at the selected nine points

(Figure 4). The average velocity rate of the largest ground displacement in area A, B and C is -3.46 ± 0.27 cm/year, -3.68 ± 0.16 cm/year and -3.21 ± 0.23 cm/year, respectively. The largest land subsidence rate could be estimated in the B area. For acquiring the local data, we carried out the damage investigation of the area B where shows the largest subsidence rate in the displacement velocity map. Figure 5 indicates the most representative deformations that were observed in the B area. The degree of deformation isn't always directly correlated with the magnitude of the displacement, but it relates to the building's firmness and maintenance. The deformed and bent wall might be by the continuous land subsidence in Nok-san reclaimed area (shown in Figure 5(a)). Even though the building built almost two decades ago, the ground that supported the building would be sunk by the land subsidence, making some apertures between the building and ground (shown in Figure 5(b)).

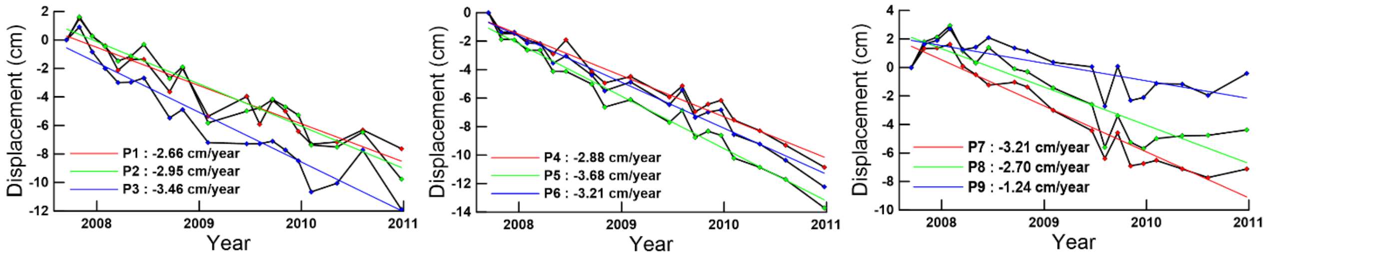

Figure 4. The time-series displacement of surface estimated in the three regions marked in the Figure 3. The scatterer plots indicate that land subsidence has been estimated at the all of selected areas. The largest subsidence rate could be estimated in the B area. Because the land subsidence rate in the area of C has been decreased since 2010, we suspect that the compaction rate of the soil sediment has been stabilized.

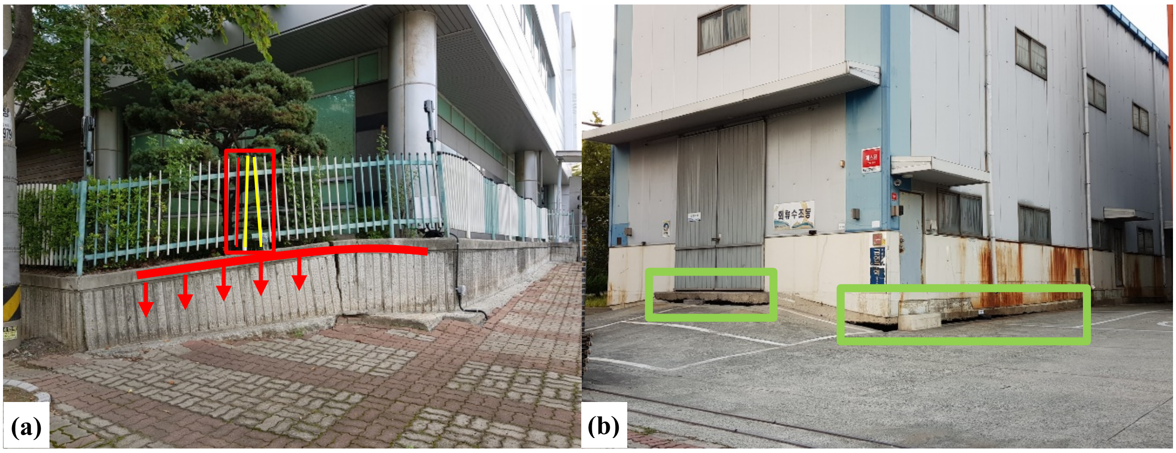

Figure 5. The suspected deformed wall and damaged building by ground subsidence observed in B area. (a) The left side of the wall was might sunk cause of the land subsidence. In the red rectangle, the original direction of the fence (red) and tilted fences direction (yellow) is different. The building in Figure 5 (b) built on Jan-2000. There are some gaps (green rectangle) beneath the building might be due to the land subsidence.

5. CONCLUSION

This paper is focused on observation of land subsidence of the Busan city in the Republic of Korea by SBAS application with ALOS PALSAR acquisitions from 15-Sep-2007 to 24-Dec-2010. Nine points which showed the significant land subsidence signals were selected to analyze the land subsidence from the displacement velocity map. The results show that significant land subsidence could be monitored in Miryang city and Nok-san. The average velocity rate showing the largest ground subsidence was -3.68 cm/year in Nok-san. In the area of C, might imply that the compaction rate of the soil sediment has been stabilized because the subsidence rate has been decreased since 2010. From the field survey, we could observe some deformations from structures which might be related to the land subsidence in Nok-san reclaimed area. We will further investigate if land subsidence is continuing. We will apply the SBAS technique using ALOS-2 PALSAR-2 ScanSAR and Stripmap dataset acquired from 09-May-2015 to 07-Sep-2019.

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