GROUND SUBSIDENCE MONITORING BY SBAS ANALYSIS IN MINING AREAS

PI No. 429

Sang-Wan Kim[1], Min-Ji Cho[1], Min-Jeong Jo[2],Hyuck-Jin Park[1]

[1] Department of Geoinformation Engineering, Sejong University
98 Gunja-Dong, Gwangjin-Gu, Seoul 143-747, Korea
Tel.: +82-2-3408-3723, Fax: +82-3408-4341, email: swkim@sejong.ac.kr
[2] Department of Earth System Sciences, Yonsei University,

ABSTRACT: There are many abandoned and operating coal mines over Gangwon province in Korea. By the field investigation the subsidence of sinkhole type can be detected well, while the subsidence of trough type could not be identified due to its very gentle and gradual settling of ground deformation. Conversely, interferometric SAR measurement is more powerful tools to detect subtle settlements of the overlying ground surface. For effective monitoring over wide areas we applied small baseline subset (SBAS) technique using 21 ALOS PALSAR data of Gangwon province during the period from October 2006 to June 2010. Fifty-five differential interferograms with a perpendicular baseline less than 1100m were constructed. As a result, we obtained a mean deformation map and time evolution of deformation at each points along LOS (Line-Of-Sight) direction over 70km × 70km wide areas. Two main subsiding areas, which are not recognized before, were clearly revealed by this map, and the continuous subsidence at a rate of 4.5cm/yr, for a total subsidence of 20 cm over 1334 day was observed at the most significant subsiding point. The RMSE with respect to linear deformation is about 1cm in overall area, and 2-3cm in densely vegetated area. Overlaying deformation map with underground mine map shows good agreement in spatial extent. Therefore, we expect that subsidence is mainly caused by mining activities in the study area.

1. INTRODUCTION

Mining activity may lead to surface deformation, changes in the local ecosystem, and have impact on manmade structures [1]. The consequence, commonly related to underground coal mining, is known as a sag subsidence, which in theory shows gentle, gradual settling of the overlying ground surface [2]. Careful monitoring and modeling of subsidence has been conducted in efforts to prevent associated disasters [3].

The majority of subsidence surveys have been conducted over limited, high-risk areas on a point-by-point basis using ground levelling and GPS techniques with accuracies of a few millimetres [4]. However, these techniques require many monitoring stations along with a surveyed baseline to produce a meaningful map of surface change. Interferometric synthetic aperture radar (InSAR) offers many advantages in measuring surface deformation. When compared with the traditional methods, it can produce an observed deformation map over a wide and continuous area. Differential interferometric synthetic aperture radar (DInSAR) using the phase difference of two correlated synthetic aperture radar (SAR) images has the ability to detect surface displacements to within a few millimetres accuracy over several kilometres [5]. Recently, these methods have been used in various fields to measure ground displacement and to retrieve three-dimensional surface information effectively [6]. However, this method has limitations such as decorrelation noise caused by random temporal variations of terrain reflectivity and atmospheric noise related to random fluctuations of atmospheric refraction. To overcome such limitations, small baseline subset (SBAS) technique has been more employed recently. The differential interferograms that are used in the time-series observation must be acquired from relatively close tracks in order to overcome spatial decorrelation [7,8].

More than 300 coal mines have been abandoned in Korea since 1989, and it has become necessary to monitor surface deformation at abandoned mines or operating mines. There are many abandoned and operating coal mines over Gangwon province in Korea, which is the mountainous area with heavy vegetation cover. By the field investigation the subsidence of sinkhole type, which is generally characterized by localized damages accompanied by small scale collapse, can be detected well, while the subsidence of trough type could not be identified due to its very gentle and gradual settling of ground deformation. Conversely, interferometric SAR measurement is more powerful tools to detect subtle settlements of the overlying ground surface. It is especially difficult to apply SAR interferometry to mountainous regions, where the branches and leaves of dense vegetation cause volume scattering, resulting in severe temporal decorrelation. Traditional DInSAR is not suitable for the measurement of ground subsidence in sites that commonly experience high temporal decorrelation. In addition, subsidence in coal mines For effective monitoring over wide areas and analyzing subsidence's time evolution we applied small baseline subset (SBAS) technique [7,8] using 21 ALOS PALSAR data of Gangwon province during the period from October 2006 to June 2010.

2. STUDY AREA AND DATASET

2. 1 Study area

The study area is located in the eastern part of South Korea defined by N36°46−N37°28’ and E128°40’−E129°30’ (Fig. 1). Figure 1 shows SAR image acquired on July 16, 2008. This area is covered in dense vegetation and the height above mean sea level is about 950 m on average. Also small scale N−S fault zones occur. Sudden surface collapse or small-scale subsidence of an order of several meters has often been reported in newspapers and official reports for this area. The reasons for this surface displacement are mostly due to underground mining activities, groundwater outflow from abandoned mines, or rock weathering in this area. The government, notably, carried out an investigation in 336 abandoned coalmine areas between 1989 and 2003 in order to prevent serious accidents (Coal Industry Promotion Board, 2004), consequently several mines were reinforced. However, more effective method is required for subsidence monitoring over broad areas that can be affected by the mining activities.

2.2 Dataset

Twenty-one ALOS PALSAR images were collected from October 11, 2006 to June 6, 2010 in Taebaek area, Gangwon (path/row = 425/730). Table 1 shows more detailed information about collected data sets. All data were co-registered to a master image acquired on July 16, 2008. Modeling was performed by matching the SAR image to a simulated SAR image derived from a digital elevation model. The 10 m DEM was constructed by interpolating 1: 25,000 digital contour maps with as a triangular irregular network.

3. DATA PROCESSING

An interferogram of SAR data is constructed by measuring the phase difference between two single-look-complex images (SLC). The surface deformation is included in the interferogram. In general, we can expect more accurate results when we analyze interferograms as many as possible, because multiple interferograms are preferred for cross-validation. In this way, the misinterpretation of topography, atmosphere, and noise as displacement could be mitigated [9]. For interferometric processing between PALSAR’s single polarization data (FBS) and dual polarization data (FBD) the FBD data was oversampled by the factor two in range.

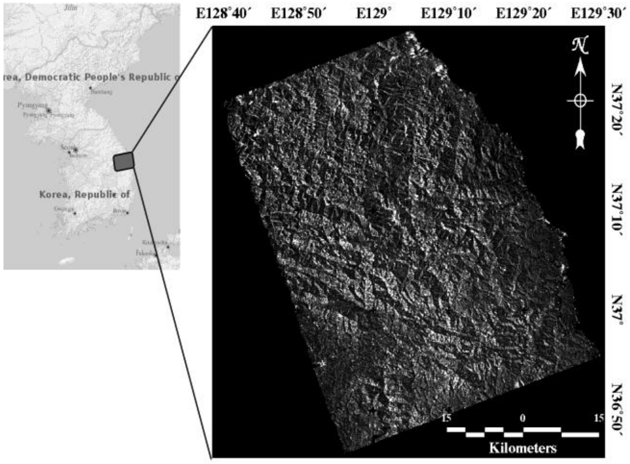

Fig. 1 Location map of the study area, seen by ALOS PALSAR single-look-complex image acquired on July 16, 2008 (Path/Row = 425/730)

We constructed a total of 79 differential interferograms with perpendicular baseline of less than 1100m. The 10-m spacing DEM constructed by 1:25,000 national digital contour maps was used to remove topographic phase. Some interferograms were of low quality due to severe temporal decorrelation. Twenty-four interferograms with low coherence were excluded from SBAS technique for corrected analysis. Figure 2 shows the pairs of fifty-five selected interferograms as described, considering the baseline and time interval of each pair. The minimum and maximum perpendicular baselines were 56m and 1096m, respectively, far below the critical baseline of 6km.

In this study, the small baseline subset (SBAS) technique was applied for the time-series analysis of surface deformations, which is utilizing Small Baseline Subset defined by a pair of data with a small orbital separation in order to reduce spatial decorrelation [8]. For example, Usai [13] defined a ‘small baseline’ of an ERS image as not exceeding about 150m in length of perpendicular

Table 1. Acquisition date of ALOS PALSAR (L-band; λ =23.53cm) data used in this study (path/row= 425/730).

No.	Acquisition Date	Beam mode	No.	Acquisition Date	Beam mode
1	2006/10/11	FBS	12	2008/12/01	FBS
2	2006/11/26	FBS	13	2009/01/16	FBS
3	2007/01/11	FBS	14	2009/03/03	FBS
4	2007/07/14	FBD	15	2009/07/19	FBD
5	2007/08/29	FBD	16	2009/09/03	FBD
6	2007/10/14	FBD	17	2009/10/19	FBD
7	2008/01/14	FBS	18	2010/01/19	FBS
8	2008/02/29	FBS	19	2010/03/06	FBS
9	2008/05/31	FBS	20	2010/04/21	FBS
10	2008/07/16	FBD	21	2010/06/06	FBD
11	2008/08/31	FBS			

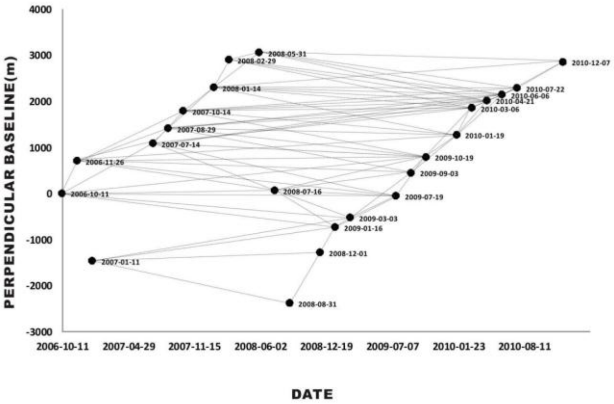

Fig. 2 Relative perpendicular baseline of ALOS PALSAR dataset. Lines indicate interferometric pair used for SBAS analysis.

baseline. In the case ALOS PALSAR, since the critical baseline is known as about 6km, interferograms with perpendicular baselines of 1km or less were considered as SB subsets in this study. For enhanced results, we used only 4-look interferograms in range to maintain the high gradient deformation in localized areas, and particularly applied the refined SBAS technique proposed by [11]. This technique also performs unwrapping error minimization and time-varying noise elimination.

4. RESULT AND DISCUSSION

Fig. 3 presents the spatial extent of the subsiding area. Interferograms from November 2006 to October 2009 present the maximum 1-fringe corresponding to about 11.8cm movement along the LOS direction. In Fig. 3 most interferograms show significant fringe patterns while the interferograms from January 2009 to March 2009 and from January 2010 to April 2010 do not show ground displacement due to a short temporal term.

As a result of the SBAS application, we obtained time evolution of deformation at each point along LOS (Line-Of-Sight) direction over 70km × 70km wide areas. In order to provide an overall image of detected subsidence, we present the mean velocity map on the shaded relief map (Fig 4a). The significant subsidence was observed in the central part of the map around Taebaek city. For the error budget analysis we simply calculated the RMSE defined by the variation with respect to linear velocity model (Fig. 4b). The RMSE is about 1 cm in overall area, and 2-3cm in densely vegetated area.

Two main subsiding areas were clearly revealed in Fig. 5, which have not been recognized by any field investigation before. The continuous subsidence at a rate of 4.5cm/yr, for a total subsidence of 20 cm over 1334 day was observed at the most significant subsiding point. The six points marked as P1-P6 in Fig. 5 were selected to monitor the deformation history in time. The time series plot (Fig. 6) shows the general trend in gradual ground displacement, but the partial displacement pattern is a little different according to the location of a selected pixel. At P1, P2, and P6 the deformation occurred from April 2007 to the early of 2008, and continued after the middle of 2009. At P3, P4, and P5 it seems that the deformation rate is decreased or stopped after the middle of 2010. To

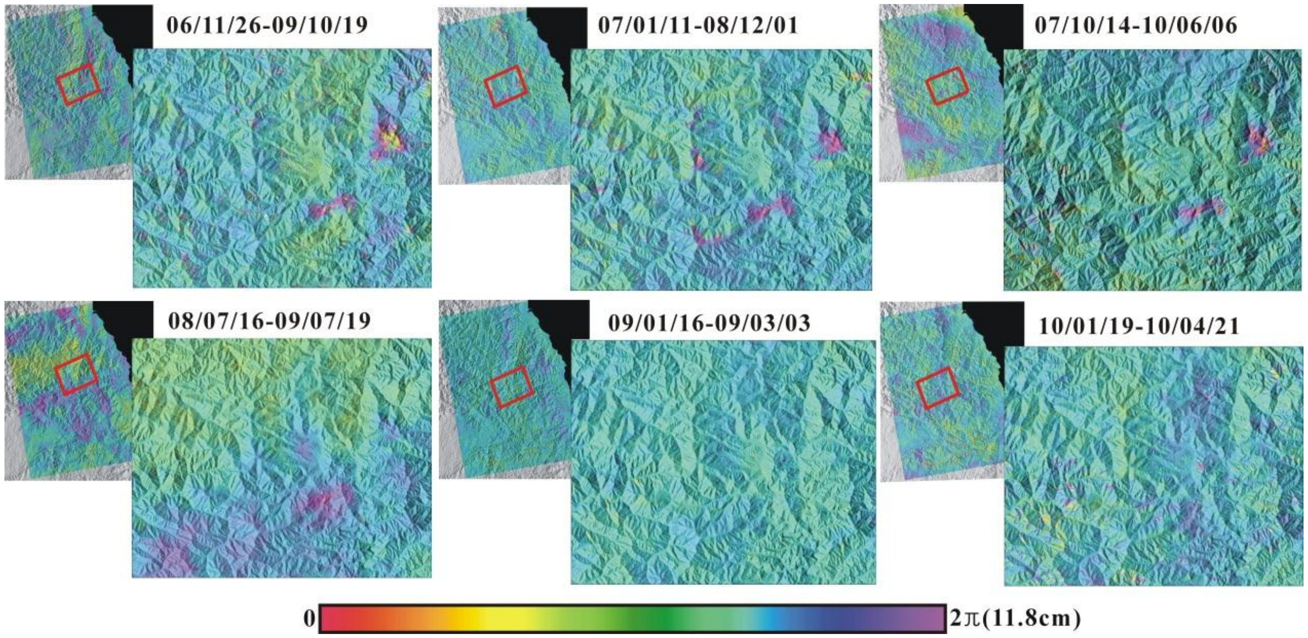

Fig. 3 Representative interferograms derived ALOS PALSAR images. Rectangle corresponds to the area of the enlarged interferogram for better observation of ground displacement. Each interferogram is overlaid on DEM

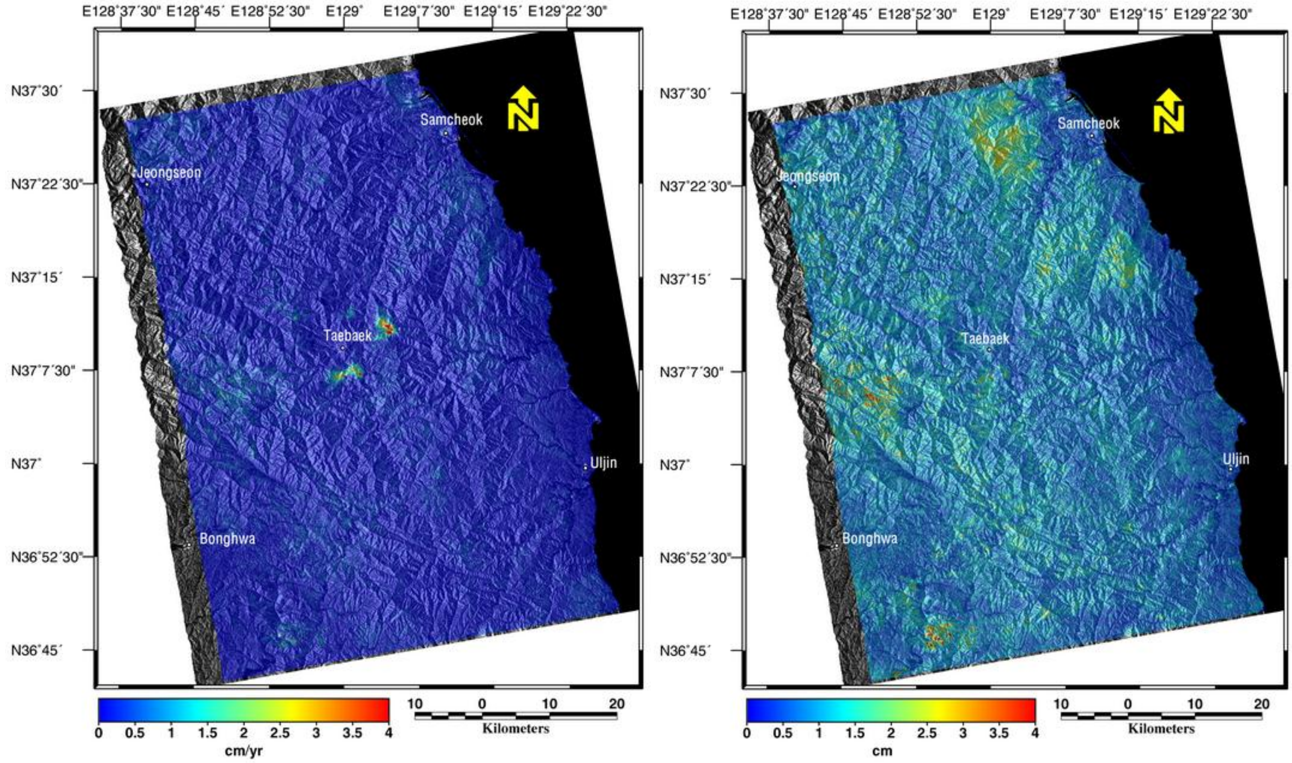

Fig. 4 (a) Linear deformation rate map from SBAS analysis, (b) RMSE map with respect to linear deformation

explain the detected subsidence the underground drift map in study area was obtained. From the overlapping of the observed deformation rate and underground drift map shown in Fig. 7 it was confirmed that the most subsiding areas were well matched with the spatial extent of underground mines. Therefore, we expect that subsidence

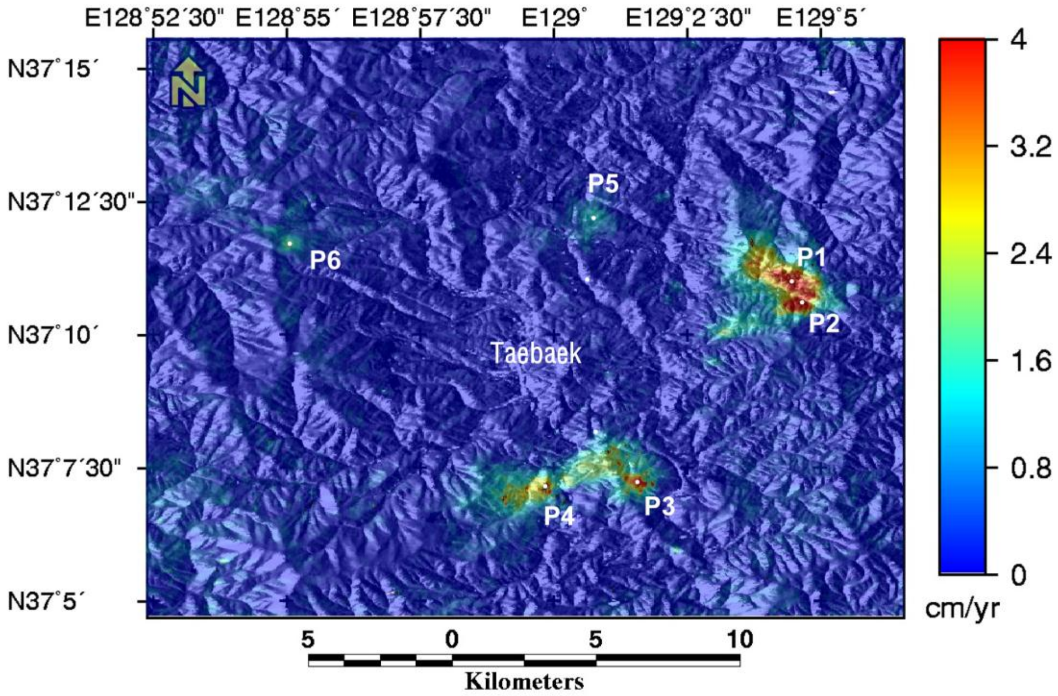

Fig. 5 Deformation rate map at major subsiding areas

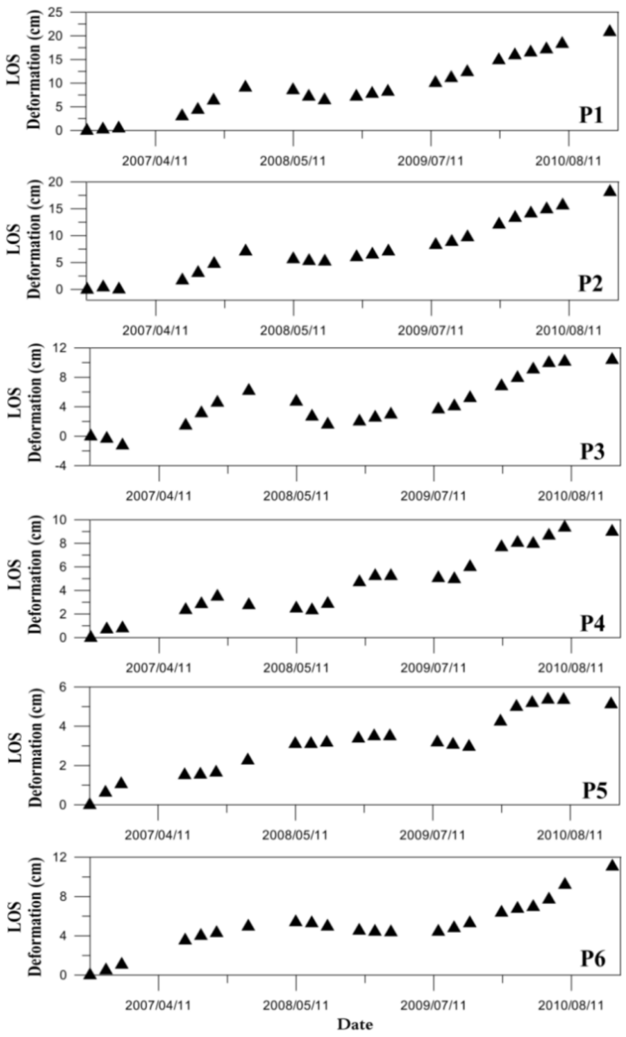

Fig. 6 Time series plots of deformation at the point P1-P6 marked in Fig. 5

is mainly caused by mining activity (Fig. 7). More detailed GIS analysis with mining map and analytical modelling of observed subsidence will be carried out as the future works.

5. CONCLUSIONS

We have performed DInSAR and SBAS technique for subsidence detection in Taebaek, Gangwon, Korea. Fifty-five interferograms have demonstrated progressive subsidence in the study area between October 2006 and June 2010. As a result of SBAS, the mean deformation map was obtained, showing continuous subsidence at a rate of 4.5cm/yr, consequently for a total subsidence of 20 cm over 1334 days at the most significant subsiding point. Although the study area is the mountainous area covered by dense vegetation, the RMSE with respect to linear deformation estimated from SBAS processing is about 1cm in overall area, and 2-3cm in densely vegetated area. From comparing deformation map with underground mine map we expect that subsidence is caused by mining activities in the study area. This study shows that InSAR analysis using multi-temporal L-band SAR is very promise tools even in the vegetated area with the accuracy of about few centimeters.

ACKNOWEDGEMENT

We thanks to JAXA(Japan Aerosapce Exploration Agency) to support ALOS PALSAR data.

REFERENCES

[1] H.C. Chang, L. Ge, and C. Rizos, “DInSAR for mine subsidence monitoring using multi-source satellite SAR images”, IGARSS 2005, Seoul, Korea, pp. 25-29, 2005

[2] Z. Perski, and D. Jura, “Identification and measurement of mining subsidence with SAR interferometry: potentials and limitations. Proceedings of the 11th FIG Symposium on Deformation Measurements”, Santorini, Greece, 2003

[3] B. Steve, and J. Kuipers, “Technical report on underground hard-rock mining: subsidence and hydrologic environmental impacts”, The center for Science in Public Participation, pp. 2–41, 2002

[4] A. Demoulin, J. Campbell, A. Wulf, A. Muls, R. Arnould, B. Gorres, D. Fischer, T. Kotter, M. Brondeel, D. Damme, and J. Jacqmotte, “GPS monitoring of vertical ground motion in northern Ardenne–Eifel: five campaigns (1999–2003) of the HARD project”, Journal of Earth Sciences, Vol. 94, pp. 515–524, 2005

[5] D. Massonnet, and K.L. Feigl, “Radar interferometry and its application to changes in the earth’s surface.” Reviews Of Geophysics, 36, pp. 441-500, 1998

[6] F. Amelung, S.H. Yun, T.R. Walter, P. Segall, and S.W. Kim, “Stress control of deep rift intrusion at Mauna Loa volcano”, Hawaill. Science, Vol. 316, pp. 1026-1030, 2007

[7] P. Berardino, M. Costantini, G. Franceschetti, A. Idoice, and V.L. Pietranera “Use of differential SAR interferometry in monitoring and modeling large slope instability at Maratea (Basilicata, Italy)”, Engineering Geology , Vol. 68 , pp. 31–51, 2003

[8] P. Berardino, G. Fornaro, R. Lanari, and E. Sansosti, “A new algorithm for surface deformation monitoring based on small baseline differential SAR interferograms”, IEEE Transactions on Geoscience and Remote Sensing, Vol. 40 , pp. 2375–2383, 2002

[9] T. Strozzi, P. Farina, A. Corsini, C. Ambrosi, M. Thuring, J. Zilger, A. Wiesmann, U. Wegmuller, and C. Werner “Survey and monitoring of landslide displacements by means of L-band satellite SAR

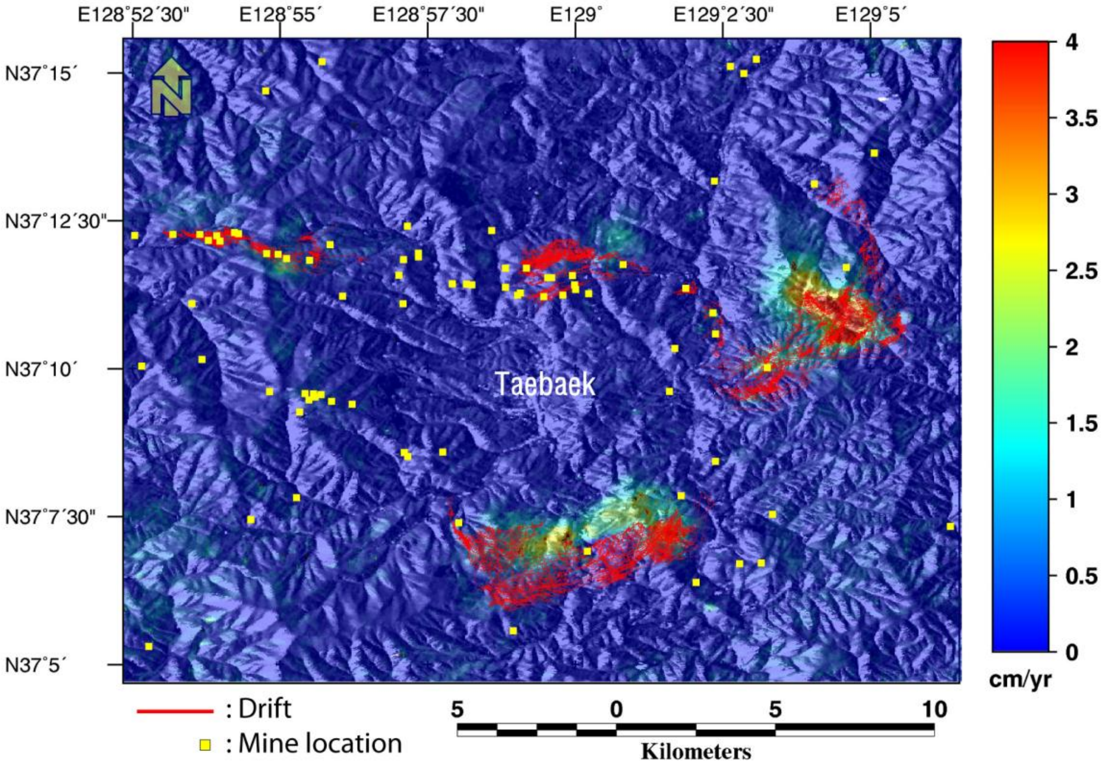

Fig. 7 Underground drift map overlaid on deformation rate map

interferometry." Landslides, Vol. 2, pp. 193-201, 2005

[10] S. Usai, "A New Approach for Long Term Monitoring of Deformations by Differential SAR Interferometry," Ph.D. thesis, Delft Unviersity, 2001

[11] H.S. Jung, C.W. Lee, J.W Park, K.D. Kim, and J.S. Won, "Improvement of Small Baseline Subset (SBAS) algorithm for measuring time-series surface deformations from differential SAR interferograms," Korean Journal of Remote Sensing, Vol. 24, No. 2, pp. 165-177, 2008