proceedings

Proceedings

Monitoring of Mining Subsidence in a Sector of Central Chile through the Processing of a Time Series of Sentinel 1 Images Using Differential Interferometry Techniques (DInSAR) †

Paulina Vidal-Páez [1,2,*], Dominique Derauw [3], Alfonso Fernández-Sarría [2] and Miguel Peralta [4]

1 Hémera Centro de Observación de la Tierra, Facultad de Ciencias, Universidad Mayor, Santiago 8340589, Chile
2 Departamento de Ingeniería Cartográfica, Geodesia y Fotogrametría, Universitat Politècnica de València, Valencia 46022, Spain
3 Centre Spatial de Liège, Université de Liège, Liège 4031, Belgium
4 Escuela de Geografía, Facultad de Arquitectura y Urbanismo, Universidad de Chile, Santiago 8331051, Chile
* Correspondence: paulina.vidal@umayor.cl; Tel.: +56-22-3281-429

† Presented at the II Congress in Geomatics Engineering, Madrid, Spain, 26–27 June 2019.

Published: 15 July 2019

Abstract: The objective of this work is to monitor the mining subsidence in a mountain range sector of central Chile between 2014 and 2018 through the processing of a time series of Sentinel 1 images using differential interferometry techniques (DInSAR). As a pretest, nine interferometric pairs were considered and processed using SNAP and SNAPHU software. Coherence levels obtained in complex topography sectors were low, due to both temporal and geometrical decorrelation. However, it is proposed that data from the PAZ project (X-band) and the Argentinean SAOCOM satellite (L-band) be used in the future.

Keywords: subsidence; Sentinel-1; DInSAR

1. Introduction

The subsidence of a mining sector is the sinking of the surface, due to the extraction of rocks or minerals from an underground mine [1]. The detection and monitoring of land subsidence make it possible to detect temporary changes in the sinking pattern and provide important information on the dynamics of this process. In addition, estimating where the future subsidence would occur would facilitate decision-making and the avoidance of damage to mining facilities and the environment [2].

The Interferometric Synthetic Aperture Radar (InSAR) is a remote sensing technique based on the process and analysis of SAR images which consists of measuring the optical path differences between the satellite and the earth, in two revisits of the satellite by the same area of study [3].

In this context, one of the techniques commonly used for this type of study in different parts of the world is differential interferometry (DInSAR), which is a technique based on synthetic aperture radar satellites that can be used to measure surface displacement in large regions with high spatial resolution. Under good conditions, displacements can be measured with centimeter to subcentimeter accuracy [4]. By monitoring the subsidence in the El Teniente mine in central Chile using the DInSAR technique during 2010 and 2015, subsidence was estimated in some sectors of up to −5 cm with TerraSAR-X and COSMO-SkyMED (X band) images [5]. When using the DInSAR technique with COSMO-SkyMED images in the same sector, an accumulated movement of −4 cm between 2010 and

2015 was estimated [6]. The objective of this research is to monitor the eventual subsidence that would occur in the mining sector in central Chile using DInSAR techniques with Sentinel-1 images.

2. Materials and Methods

2.1. Study Area

The study area corresponds to a mining sector of the Libertador General Bernardo O'Higgins Region located in the central zone of Chile between 34°1′18″ and 34°12′57″ south latitude and 70°28′18″ and 70° 28′29″ West longitude (Figure 1). This sector has a Mediterranean climate (warm summers) with mountain influence [7].

The mining sector corresponds to an underground copper mine with a processing capacity of 140,000 tonnes per day [8].

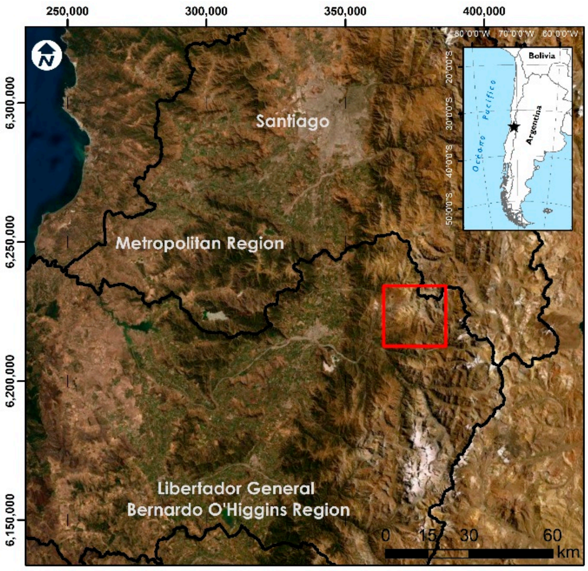

Figure 1. Study area. The red rectangle shows the study area.

2.2. Acquisition of Images

Nine interferometric pairs generated from SAR images of the Sentinel-1 satellite (Table 1), C-band (5.405 GHz) in Interferometric Wide Swath (IW) acquisition mode with Single Look Complex (SLC) processing level with 5 × 20 m spatial resolution and VV polarization were used for this study. The images were downloaded from the free Alaska Satellite Facility server.

Table 1. Characteristics of interferometric pairs used.

Pair	Date (dd-mm-yyyy)	Flight Direction	P_b [1]	T_b [2]	Pair	Date (dd-mm-yyyy)	Flight Direction	P_b	T_b
1	06-10-2014 30-10-2014	Ascending	130	24	6	10-01-2017 03-02-2017	Descending	21	24
2	23-10-2014 16-11-2014	Descending	90	24	7	10-01-2017 27-02-2017	Descending	16	48
3	10-01-2015 03-02-2015	Ascending	130	24	8	05-02-2018 01-03-2018	Ascending	67	24
4	03-01-2015 20-02-2015	Descending	19	48	9	05-01-2018 29-01-2018	Descending	69	24
5	17-01-2016 10-02-2016	Ascending	34	24					

[1] P_B: Perpendicular baseline. [2] T_B: Temporal baseline.

2.3. Formation of Interferograms and Estimation of Displacement

Nine interferometric pairs were used from 2014 to 2018 to study subsidence in a mountain range sector in central Chile. The interferometric pairs were processed independently in the SNAP (Sentinel Application Platform) software developed by ESA, and the SNAPHU software [9] was used to phase unwrapping. Figure 2 shows the steps applied to interferometric pairs using the DInSAR technique.

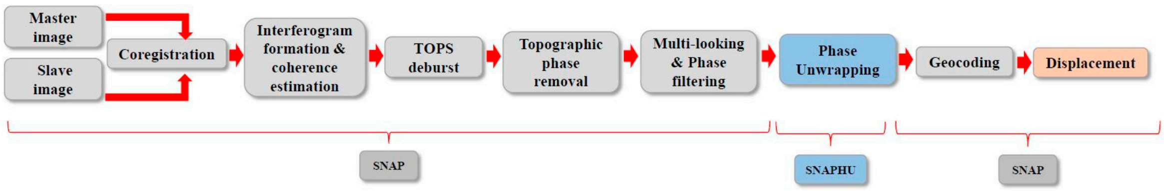

Figure 2. Methodology for the estimation of subsidence in the mining sector.

3. Results

Nine interferograms generated from Sentinel-1 images with VV polarization, both descending and ascending pairs, were processed between 2014 and 2018. Due to time laps between acquisitions and geometrical decorrelation in this complex relief area, observed coherence level in the mining sector under study is less than 0.5 as shown in Figure 3. This is observed both in the descending and ascending pairs and to obtain displacement, coherence values greater than 0.5 should be considered, since these values are considered a good indicator of the interferometric phase quality [10].

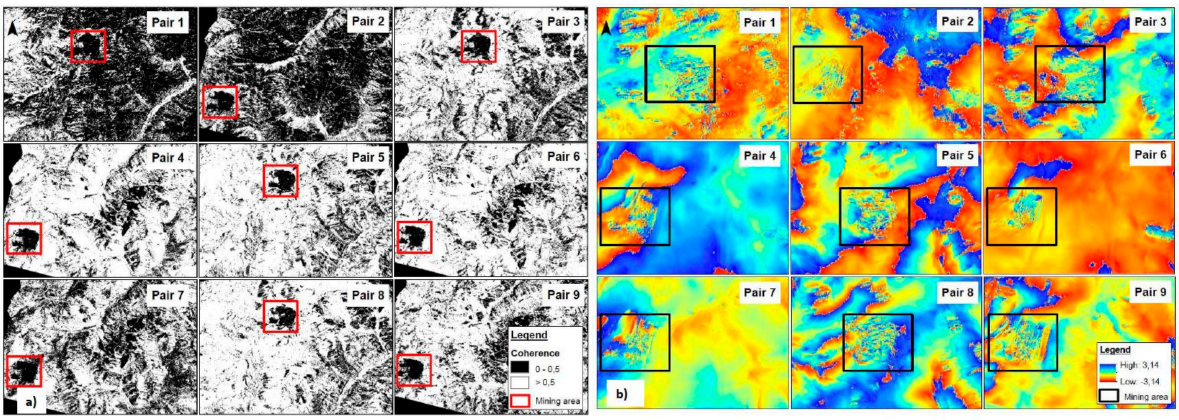

Figure 3. (**a**) Binary coherence mask; black: coherence < 0.5, withe: coherence ≥ 0.5; (**b**) Interferograms in the study area.

Figure 3 shows the interferograms obtained from the nine interferometric pairs, with a low correlation in the mining sector, as a result of the low coherence in the sector. This low coherence is mainly due to time and geometric decorrelation. Due to these factors, it was not possible to measure displacement (subsidence) in this sector.

4. Discussions and Conclusions

Free and open access to the Sentinel-1 images allowed for a large amount of data in the study area, however, the levels of coherence obtained in sectors of complex topography were low (<0.5), due to time and geometric decorrelation, so it was not possible to estimate the subsidence in the mining area, even when using C-band. A study carried out in a mining sector in the Metropolitan Region of Chile, where TerraSAR-X and Sentinel-1 data used the MSBAS technique, obtained coherence values lower than 0.45 so it was not possible to completely remove the topographic phase in order to obtain the differential phase to estimate the subsidence [11].

Another study has estimated the subsidence through the DInSAR technique in the mining sector under study with COSMO-SkyMED images (X-band), where subsidence of up to −4 cm is monitored in some sectors [6]. However, these images are commercial and have a spatial resolution of up to 1 m.This work corresponds to the preliminary results of the first-year doctoral research and It is proposed that data from the PAZ project (X-band), the Argentinean satellite SAOCOM (L band), the MSBAS and PSI techniques, different software and all interferometric pairs available, be used in the future, which would improve surface deformation analyses like those of subsidence.

Author Contributions: Conceptualization, P.V.; methodology, P.V., D.D. and A.F.-S.; software, P.V. and M.P.; validation, P.V., D.D. and A.F.-S.; formal analysis, P.V.; investigation, P.V.; resources, P.V.; writing—original draft preparation, P.V.; writing—review and editing, P.V.; D.D. and A.F.-S.; visualization, P.V.; supervision, D.D. and A.F.-S.

Acknowledgments: The work was supported by the Centro de Observación de la Tierra Hémera de la Universidad Mayor.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Ng, A.H.-M.; Ge, L.; Du, Z.; Wang, S.; Ma, C. Satellite radar interferometry for monitoring subsidence induced by longwall mining activity using Radarsat-2, Sentinel-1 and ALOS-2 data. *Int. J. Appl. Earth Obs. Geoinf.* **2017**, *61*, 92–103, doi:10.1016/j.jag.2017.05.009.
2. Sarychikhina, O.; Glowacka, E.; Mellors, R.; Vidal, F.S. Land subsidence in the Cerro Prieto Geothermal Field, Baja California, Mexico, from 1994 to 2005. An integrated analysis of DInSAR, leveling and geological data. *J. Volcanol. Geotherm. Res.* **2011**, *204*, 76–90, doi:10.1016/j.jvolgeores.2011.03.004.
3. Ferretti, A.; Monti-Guarnieri, A.; Prati, C.; Rocca, F. *InSAR Principles: Guidelines for SAR Interferometry Processing and Interpretation*; TM-19; ESA Publications: Noordwijk, The Netherlands, 2007; ISBN 92-9092-233-8.
4. Wempen, J.M.; McCarter, M.K. Comparison of L-band and X-band differential interferometric synthetic aperture radar for mine subsidence monitoring in central Utah. *Int. J. Min. Sci. Technol.* **2017**, *27*, 159–163, doi:10.1016/j.ijmst.2016.11.012.
5. Espinosa, E.A.; Manso, G.A. Ground Subsidence Model for a Panel Caving Exploitation at el Teniente Mine—Codelco Chile. In Proceedings of the 49th U.S. Rock Mechanics/Geomechanics Symposium, San Francisco, CA, USA, 28 June–1 July 2015; American Rock Mechanics Association: Alexandria, VA, USA, 2015.
6. Sánchez, F.; Conde, A.; Salvà, B.; Colombo, D. Use of SAR Radar satellite data to measure ground deformation in underground and open pit mine sites, El Teniente case study, Chile. In Proceedings of the First Asia Pacific Slope Stability in Mining Conference, Brisbane, Australia, 6–8 September 2016.
7. Sarricolea, P.; Herrera-Ossandón, M.; Meseguer-Ruiz, Ó. Climatic regionalisation of continental Chile. *J. Maps* **2017**, *13*, 66–73, doi:10.1080/17445647.2016.1259592.
8. Comisión Chilena del Cobre. *Inversión en la Minería Chilena-Cartera de Proyectos 2014–2023*; Comisión Chilena del Cobre: Chile, South America, 2014.
9. Chen, C.W.; Zebker, H.A. Network approaches to two-dimensional phase unwrapping: Intractability and two new algorithms. *J. Opt. Soc. Am. A* **2000**, *17*, 401–414, doi:10.1364/JOSAA.17.000401.
10. Crosetto, M.; Crippa, B. Quality Assessment of Interferometric SAR DEMs. *ISPRS J. Photogramm. Remote Sens.* **2000**, *33 Pt B1*, 46–53.
11. Universidad Mayor. *Estudio de Geología, Geomorfología y Peligros Naturales en la cuenca Alta del río Mapocho*; Inédito: Chile, South America, 2018.