Monitoring surface deformation of an active landslide in the Yerba Loca area, Chile, using DInSAR technique with PAZ imagery

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***Abstract*— Landslides in steep slope areas provide significant risks to infrastructure and ecosystems, especially in mountain regions. Monitoring techniques based on Differential Interferometric Synthetic Aperture Radar (DInSAR) and Small Baseline Subset (SBAS) processing have proven to be valuable tools for the detection and monitoring of deformation associated to such events.**

This study analyzes the deformation patterns of an active landslide in the Yerba Loca basin, a mountainous Andean region susceptible to mass movements.

Based on the analysis of 41 SAR PAZ images, covering the period between October 2019 and April 2021, we observed that the landslide exhibits a cumulative vertical displacement of -16.5 mm and a horizontal displacement in the east-west direction of approximately -13 mm, with average velocities of ~9.6 mm/year and ~6.3 mm/year, respectively.

The results suggest that the landslide remains active and its movement is likely associated with the steep slopes characteristic of the area, highlighting the importance of implementing continuous monitoring in the region.

***Keywords*— PAZ images, DInSAR, SBAS, landslide.**

I. Introduction

Landslides are common geological phenomena in mountainous areas [1, 2, 3] and represent a significant threat to communities, infrastructure, and ecosystems. A notable example of a region susceptible to such events is the Yerba Loca basin, located in the Andes of central Chile. This basin is characterized by rugged topography, with steep slopes ranging between 20° and 40°, and landscapes shaped by glacial, alluvial and alluvio-glacial processes and landslides [4]. These processes have left numerous landslide deposits scattered across the valley slopes throughout the entire basin [4]. In January 2012 alone, 15 landslides were documented [5] in the area, with activity extending through 2023 [6]. Among them, the Yerba Loca slide stands out as a multirotational event which started its movement in August 2018, with an estimated volume of 2.5 million m³ [7, 8] and a displacement of approximately 28 cm [9].

Advanced techniques such as Differential Synthetic Aperture Radar Interferometry (DInSAR) have been widely used to monitor ground displacements in areas that are difficult to access [3, 9, 10, 11, 12, 13]. The primary objective of this study is to analyze the deformation patterns of an active landslide in the Yerba Loca basin using 41 SAR PAZ images, acquired between October 2019 and April 2021, processed with the Small Baseline Subset (SBAS) differential interferometry technique.

II. Materials and Methods

A. Study area

The study area is located within the Yerba Loca Sanctuary, situated in the eastern zone of Central Chile, between 33°10’

and 33°20’ south latitude and between 70°10’ and 70°20’ west longitude, in the Andes (Figure 1a). This is a high-mountain area, whose geology is characterized by reflecting the evolution of the Abanico Basin during the Eocene-Oligocene, with ubiquitous arc magmatism in the Miocene and compressive deformation regimes in the Early to Middle Miocene, which have generated a series of faults and folds in the area [4]. These geological structures have controlled the geomorphological development of the basin, influencing glacial, alluvial, and fluvial erosion and sedimentation processes in the Pleistocene-Holocene. All of these are highly dynamic due to the periglacial climatic conditions [4] that shape the region's relief. In addition, more than 50% of the area has slopes greater than 20°, with the majority ranging between 20° and 40°.

In this sector, an active landslide has been observed (Figure 1b), covering 0.04 km² and with a perimeter of 0.83 km. This landslide is located on the northeast-facing flank in the northern part of the Yerba Loca Sanctuary (Figure 1c and d) and associated with the rotational slide that occurred in 2018 in the same sector [7,8,9].

B. Data collection

For the analysis, 41 SAR images from the Spanish PAZ satellite were used: 19 of ascending orbit and 22 of descending orbit. These images cover the period from September 17, 2019, to April 24, 2021, for ascending orbit images, and from September 17, 2019, to June 5, 2019, for descending orbit images. The master images correspond to November 22, 2019, and December 11, 2020, respectively.

The images were provided by the National Institute for Aerospace Technology of Spain, under Announcement of Opportunity AO-001-050. They have a spatial spacing of 1.7 x 1.9 m (in range and azimuth), covering an area of 30 km x 50 km.

These images operate in the X band (9.65GHz) and use the *Stripmap* (SM) acquisition mode and S*ingle Look Slant Range Complex* (SSC) processing.

C. SBAS processing

To estimate displacement and velocity components in both the vertical (Up-Down) and east-west (E-W) directions, the Small Baseline Subset (SBAS) algorithm [14] was employed using the ENVI SARScape 5.7® software. SBAS is an advanced DInSAR technique that generates high-precision time series of ground displacements by selecting interferometric pairs with small spatial and temporal baselines. This strategy reduces errors from orbital inaccuracies and atmospheric disturbances, while improving interferometric coherence—making it particularly effective for monitoring slow, continuous surface deformations over time [15].

After obtaining displacement time series along the satellite's line of sight (LOS) from both ascending and descending orbits of the PAZ satellite, a process known as Displacement Decomposition was applied. This method allows the separation of LOS displacement into its vertical (Up-Down) and horizontal (East-West) components. By combining information from the two viewing geometries, the decomposition resolves the true ground motion directions, under the assumption that the North-South displacement is negligible or secondary. This step is essential for understanding the physical nature and directionality of observed surface movements [16].

III. RESULTS

Based on the analysis of 41 SAR PAZ images, between October 2019 to April 2021, the vertical displacement component (Up-Down) and east-west (E-W) displacement were estimated.

Figure 2a shows that, at the control point, the cumulative vertical displacement reaches -16.5 mm during the study period, with an approximate vertical displacement velocity of ~-9.6 mm/year (Figure 2c). It is important to note that negative values indicate subsidence in the area suggesting that the slide is still active.

On the other hand, a displacement in the east-west direction of approximately ~-13 mm is observed (Figure 2b), with an estimated velocity of ~-6.3 mm/year (Figure 2d) which suggests that the landslide also moves in the main direction of the slope.

Additionally, Figure 3 presents the trend of vertical and horizontal displacements over the study period. In the vertical component displacement trend, there is an acceleration in subsidence between May and June 2020, which continues until August of the same year. In the case of the E-W component displacement, there is an acceleration period that starts in December 2019 and continues until mid-January 2020.

The minimum value of the time series displacement (Figure 3), for both the vertical and horizontal component displacements, is smaller than the maximum observed displacement in Figure 2 because of the monitoring point location.

Figure 2a shows a concentric vertical deformation pattern where the landslide has a lobular shape with a scarp of approximately 50 meters high (Figure 1c, d) with slopes ranging between 20° and 40°.

The resulting deformation pattern can be attributed to the geological and geomorphological conditions of the area, characterized by a periglacial environment with dynamic processes of alluvial, glacial, and fluvial origin. These processes can lead to phenomena such as gelifluction and permafrost presence which, combined with the steep slopes of the area, can trigger landslide events like the one analyzed.

IV. CONCLUSIONS AND DISCUSIONS

In this study, the displacement pattern of an active landslide located in the Yerba Loca basin, in the Andes of central Chile, was analyzed. This area is characterized by frequent mass movements [1, 2, 3, 4, 5, 6], such as the Yerba Loca Landslide, which displaced initially up to 2.5 million m³ in August 2018 [7, 8, 9].

Using the SBAS DInSAR landslide monitoring technique, applied to 41 SAR images from the PAZ satellite for the period between October 2019 and April 2021, it was determined that the landslide exhibits a vertical deformation of -16.5 mm, with an average velocity of ~-9.6 mm/year, indicating subsidence and therefore that the landslide is still active. Additionally, horizontal deformation in the east-west direction of approximately -13 mm was recorded, with an average velocity of ~-6.3 mm/year. Furthermore, the acceleration in E-W displacement coincides with the period of snow and/or permafrost melting. An acceleration period in vertical displacement was also identified between May and June 2021.

It is worth highlighting some of the advantages of the DInSAR technique combined with the SBAS method for monitoring active landslide areas, such as its wide spatial coverage, the ability to conduct analyses across different temporal series, its high sensitivity to millimetric displacements due to the high resolution of the images, and its capacity for remote monitoring, among others [3, 9, 10, 11, 12, 13]. Furthermore, monitoring landslide events using SAR images has proven to be an effective tool for the early detection of landslides in remote areas, as well as for identifying potential precursor signals. However, it is important to consider the inherent limitations of this method, such as the geometric effects associated with the use of the images [13].

We are currently comparing the deformation results obtained from PAZ and Sentinel-1 (S1) images, which show a high level of consistency in both the spatial pattern of landslide deformation and the magnitude of the detected displacements.

In conclusion, this study demonstrates that the SBAS DInSAR technique, using SAR images, is an effective tool for monitoring active landslides in high mountain areas, such as the one in the Yerba Loca basin. The results obtained, which show both vertical and horizontal deformations, demonstrate the importance of this technique for identifying and quantifying displacement patterns with high precision. Moreover, the analysis over time allows the detection of potential accelerations in movement, which is crucial for evaluating the dynamic behavior of these zones and their variations through time.

Although the technique presents certain limitations, combining SBAS DInSAR data with field observations and measurements enhances the interpretation and validation of the results. These features make this technique to be a valuable tool for studying mass movement processes, contributing significantly to risk management in mountain and/or remote areas.

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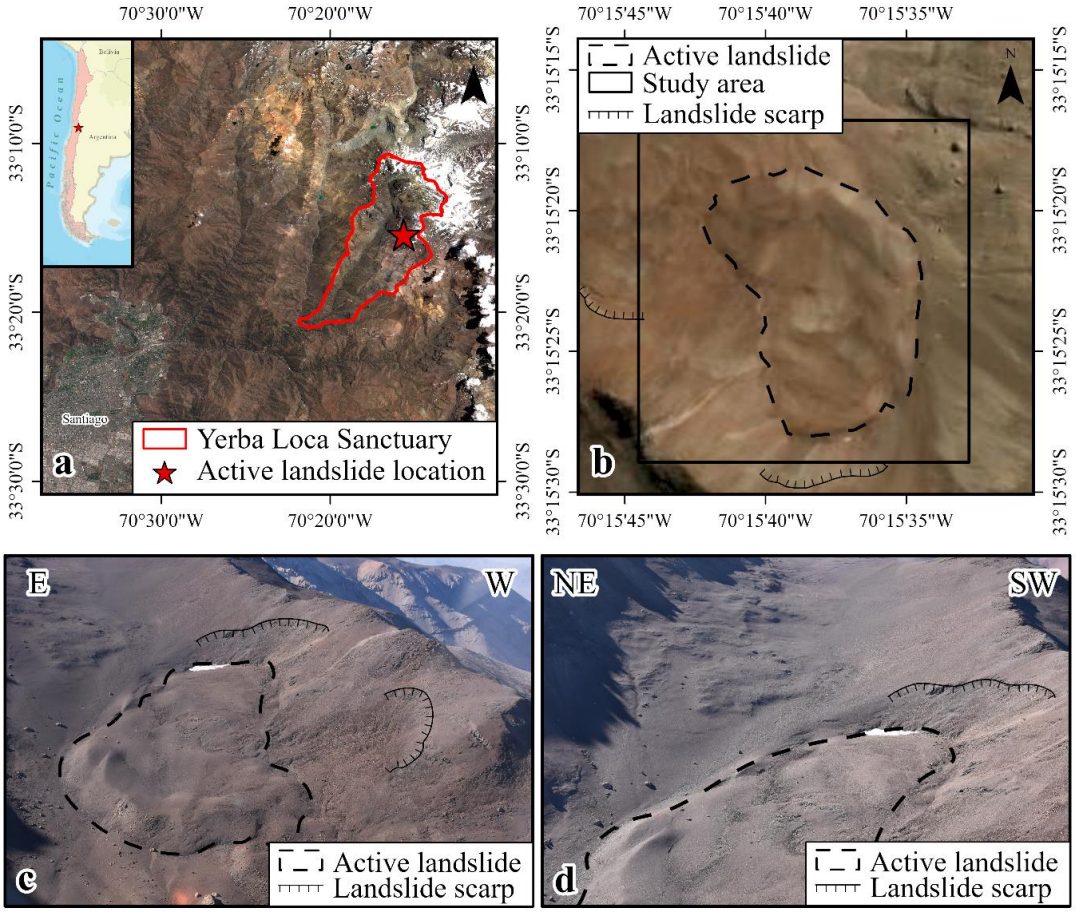


Fig. 1. A. Location of the study area in the Yerba Loca basin in central Chile. B Close-up of the landslide and landslide scarp from satellite imagery. C. Aerial photo taken in January 2023 showing active landslide and scarp. D. Aerial photo taken in January 2023, showing a close-up of the scarp.

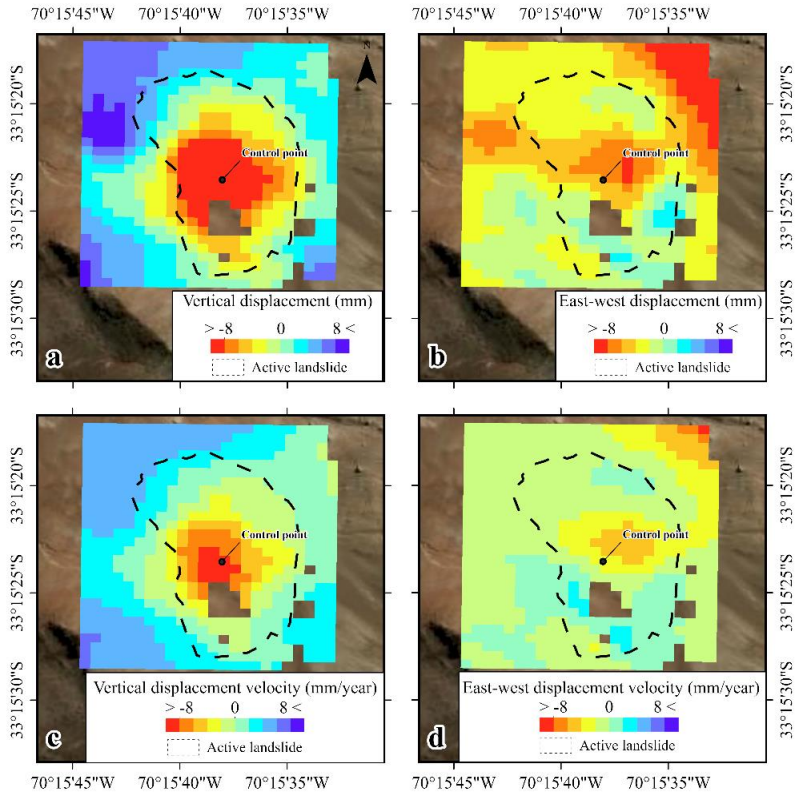


Fig. 2. Deformation analysis of active landslide in the study area. A. Vertical displacement (mm). B. East-West displacement (mm). C. Vertical displacement velocity (mm/year). D. Displacement velocity in East-West direction (mm/year).

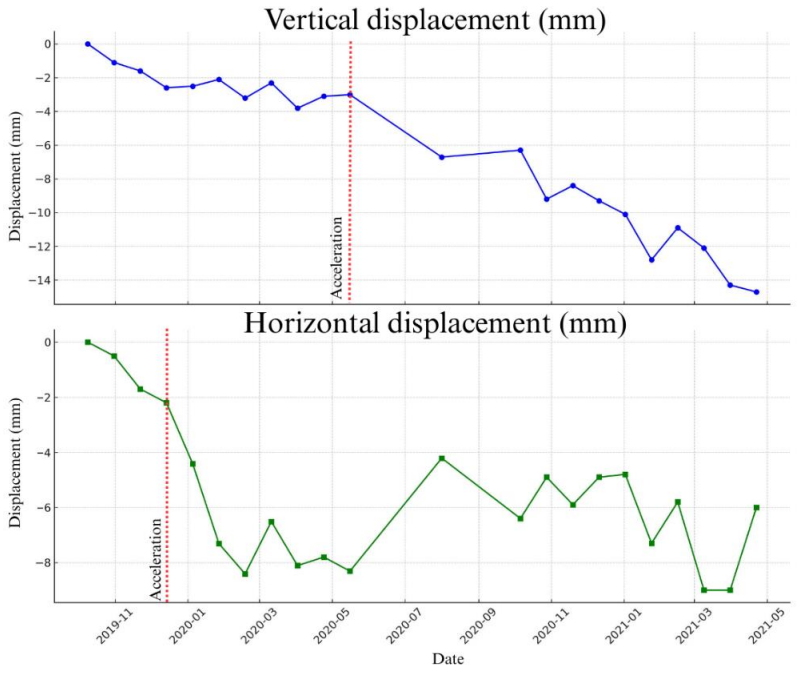


Fig. 3. Vertical and horizontal displacement trend at control point in active landslide.

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