# InSAR Monitoring of the Integral's Ituango Dam in Antioquia, Colombia

Report Submitted: 30 March 2022

## Submitted to:

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# 1 Executive Summary

This Comprehensive Report provides the results of advanced InSAR techniques used to monitor displacement over the Ituango Dam for Integral S.A.

| | |
|---|---|
| **Client Name** | Integral S.A. |
| **Site Name** | Ituango dam |
| **Site Location** | Antioquia, Colombia |
| **Product Type** | Dual Look Comprehensive |
| **SAR Sensor** | ALOS-2 |
| **Number of Footprints** | 2 |
| **Pass Direction** | Ascending Left-Looking and Ascending Right-Looking |
| **Number of images** | 23 & 31 |
| **Reporting Period** | 4 July 2020- 26 February 2022 |
| **Report Frequency** | Quarterly |
| **Rate Scale** | +/- 50 cm/yr |
| **SNR Displacement Extent** | 4.0 Sigma |
| **Number of Points in Database** | 18,198,106 |
| **Number of Points in KMZ** | 15,000 |
| **Overall Data Quality** | High |

# 2 Introduction

This Comprehensive Report provides results of advanced InSAR techniques used to monitor displacement over the Ituango Dam in Antioquia, Colombia. The data was collected by the ALOS-2 satellite covering the footprints shown in Figure 2.1 from July 4, 2020 until February 26, 2022. This report summarizes the data used and the displacement results generated.

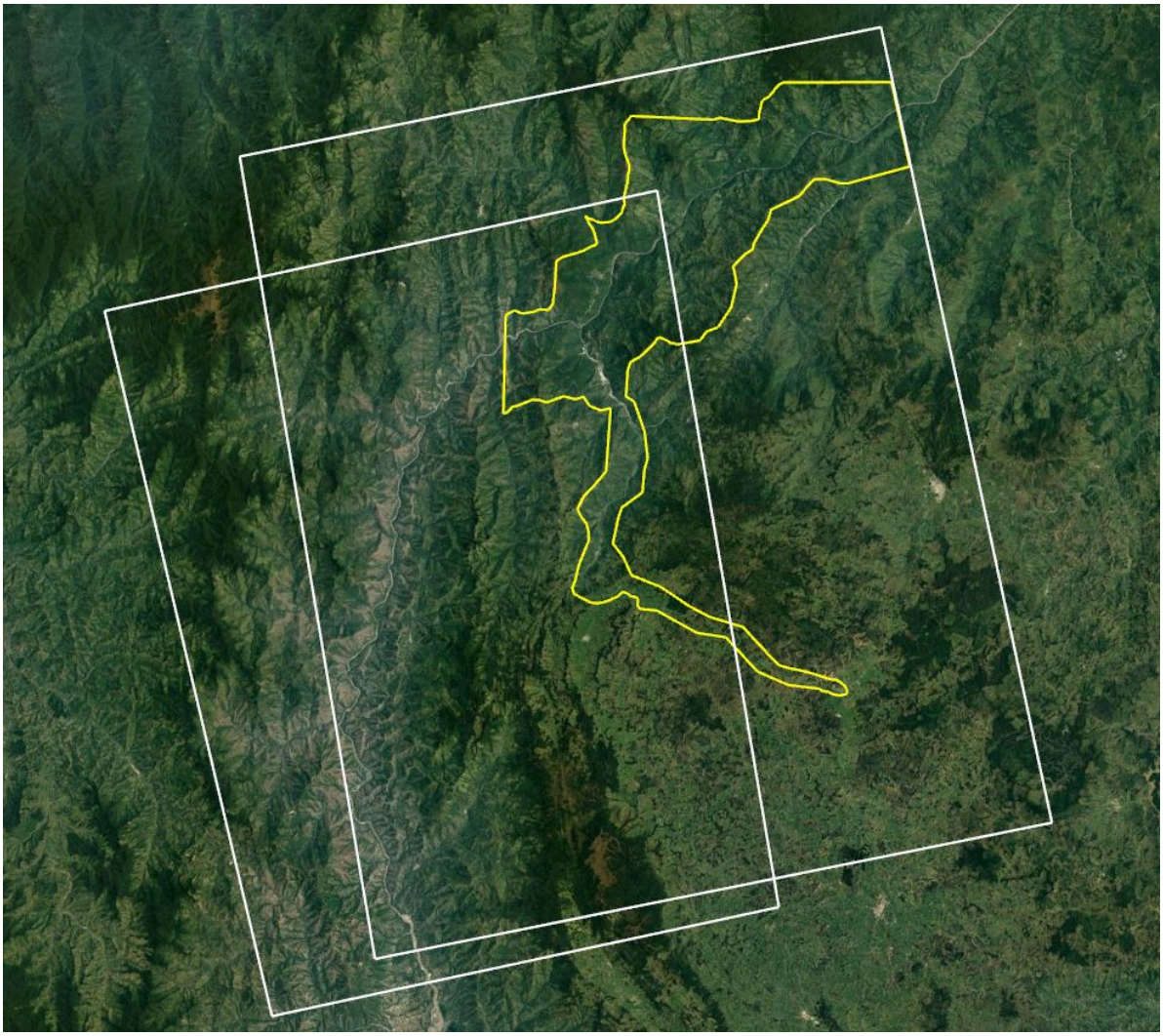

**Figure 2.1:** The ALOS-2 footprints (white) and the area analyzed (yellow) are shown over the Google Earth optical imagery.

While this document highlights some of the results, the 3vG Product User Manual contained within the Resources section of the delivery folder, describes the products in more detail. The 3vG Arcmap Comprehensive Tools manual describes how to install and use the toolbar in ArcMap.

# 3 Deliverables

Displacement Products:

- **ituango_20220226_Data**: Database containing all GIS data needed by the ArcMap project file (.mxd). The ArcMap project and 3vG toolbar require that all GIS data within this folder remains unchanged.
- **ituango_20220226_MapProject.mxd**: An ArcMap project file set up to access and display the accompanying data.
- **ituango_20200704_20220226_Comprehensive_Report.kmz**: Time series of the selected cumulative point displacements and displacement rates to date, compatible with Google Earth.
- **ituango_20200704_20220226_extents_4_0_SNR.shp**: Contour lines indicating the extents of significantly sized areas of confirmed displacement, in dxf format.
- **ituango_20200704_20220226_Rate_50_0cmpy.tif**: RGB color mapped GeoTIFF of the absolute displacement rate.
- **ituango_20200704_20220226_Rate_cmpy.tif**: Data GeoTIFF of the absolute displacement rate.
- **ituango_20200704_20220226_PointDisplacement<_without_xo>.csv**: List of the cumulative displacement of selected points throughout the mine over time, in CSV text format. Delivered with and without x and o interpolation characters.
- **ituango_20200704_20220226_PointVelocity.csv**: List of the instantaneous velocity of selected points throughout the mine over time, in CSV text format.

**Resources**

- **3vGCompTools.esriaddin**: A tool to assist with data visualization and analysis in ArcMap 10.5+.
- **3vG.style**: An auxiliary file used by the toolbar to apply the 3vG color ramp to date within the ArcGIS ap project.
- **3vG_Arcmap_Comprehensive_Tools_Manual.pdf**: Documentation for installation and use of 3vG's dd-in tools.
- **3vG_Product_User_Manual.pdf**: Documentation describing 3vG's products and their intended use.
- **3vG_InSAR_Guide.pdf**: Documentation describing the fundamental concepts of InSAR.

# 4 Satellite Data

The SAR data used for monitoring Ituango Dam is acquired by the Japanese L-Band ALOS-2 Satellite in Stripmap mode. Stripmap has a resolution of 3 m, an image footprint of 55 km x 70 km, a wavelength of 22.9 cm and a revisit time of 14 days.

This quarterly Comprehensive Report details processing and results derived from 23 left-looking and 30 right-looking ascending SAR images acquired over the dam and reservoir. The SAR images included in this analysis are summarized in Tables 4.1 and 4.2 and Figure 4.1.

**Table 4.1: Ascending, left-looking SAR images used for this analysis. Grey cells indicate images which were included in the previous delivery.**

| | | | | | |
|---|---|---|---|---|---|
| 12 Jul 2020 | 09 Aug 2020 | 20 Sep 2020 | 18 Oct 2020 | 01 Nov 2020 | 15 Nov 2020 |
| 29 Nov 2020 | 10 Jan 2021 | 21 Feb 2021 | 07 Mar 2021 | 21 Mar 2021 | 04 Apr 2021 |
| 18 Apr 2021 | 13 Jun 2021 | 27 Jun 2021 | 25 Jul 2021 | 22 Aug 2021 | 19 Sep 2021 |
| 17 Oct 2021 | 28 Nov 2021 | 09 Jan 2022 | 23 Jan 2022 | 06 Feb 2022 | |

**Table 4.2: Ascending, right-looking SAR images used for this analysis. Grey cells indicate images which were included in the previous delivery.**

| | | | | | |
|---|---|---|---|---|---|
| 04 Jul 2020 | 15 Aug 2020 | 12 Sep 2020 | 10 Oct 2020 | 24 Oct 2020 | 07 Nov 2020 |
| 21 Nov 2020 | 05 Dec 2020 | 19 Dec 2020 | 02 Jan 2021 | 16 Jan 2021 | 30 Jan 2021 |
| 13 Feb 2021 | 27 Feb 2021 | 13 Mar 2021 | 10 Apr 2021 | 08 May 2021 | 05 Jun 2021 |
| 19 Jun 2021 | 03 Jul 2021 | 14 Aug 2021 | 11 Sep 2021 | 25 Sep 2021 | 09 Oct 2021 |
| 06 Nov 2021 | 20 Nov 2021 | 01 Jan 2022 | 15 Jan 2022 | 29 Jan 2022 | 26 Feb 2022 |

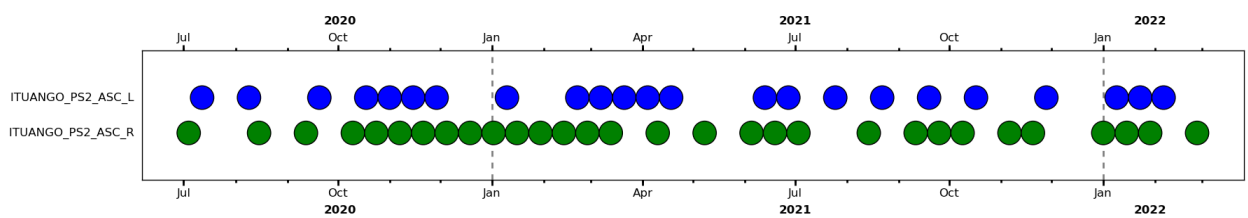


**Figure 4.1:** Spread of SAR images for ALOS-2 data. Touching circles indicate successive 14-day acquisitions.

Note that despite the 3 m pixel size a cluster of pixels of displacement signal is required for the displacement to be detected by our processing algorithms. For the 3 m resolution of ALOS-2 in SM-1 mode, the standard minimum area that can be detected is 25 m x 25, or 625 $m^2$.

# 5 Results

The following section provides an overview of the results over this reporting period. The full results are contained within a Google Earth KMZ, an SQLite database and on the online Motionary2 platform. For a detailed description of these products please refer to the 3vG Product User Manual, included with this delivery.

## 5.1 Displacement Rate

Figure 5.1 shows the absolute displacement rate over the Ituango Dam, displayed in Google Earth. The Google Earth file contains a number of features to assist in the interpretation of the results including the displacement rates, displacement time series and displacement direction information. To avoid overloading Google Earth, only 15,000 of the measurable points are presented in the KMZ file. All points analyzed, including the points that are not included in the KMZ, are delivered in the SQLite database and on the Motionary2 platform.

Since some areas experience high magnitudes of displacement, areas of lower magnitude would be hidden without a color scale biased towards the lower end. In order to make these areas more visible, the default color scale has been set to 0 to 50 cm/yr in Google Earth (Figure 5.1), allowing high magnitude displacement areas to saturate, but enhancing subtle displacement areas. This value and the color scale can be adjusted in ArcMap using the 3vG toolbar.

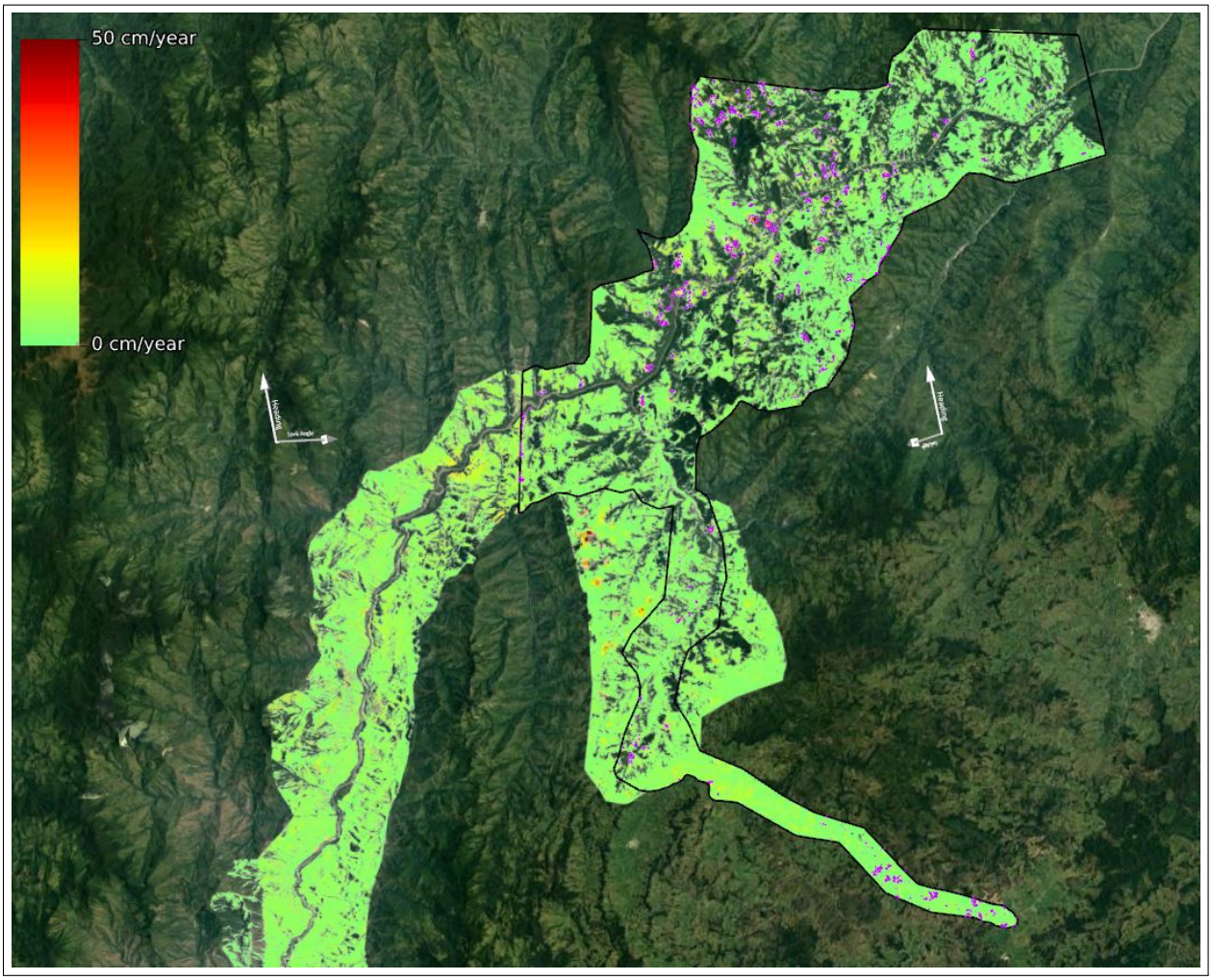


**Figure 5.1:** The absolute displacement rate over the AOI, viewed in Google Earth.

To assist in the identification of high confidence areas of displacement, a displacement extents layer is included. The purple polygons (Figure 5.1) indicate areas where 3vG has a high degree of confidence that displacement is occurring.

## 5.2 Displacement in Critical Areas of Interests

The following section provides an analysis of the displacement rates in the critical areas of interest provided by Integral.

**Displacement Area over DAM**

Displacement within the critical area of interest over DAM continues to grow during this reporting period. As shown in Figure 5.2, displacement started picking up again around July and it is moving at displacement rates of 16 cm/yr towards down-east direction.

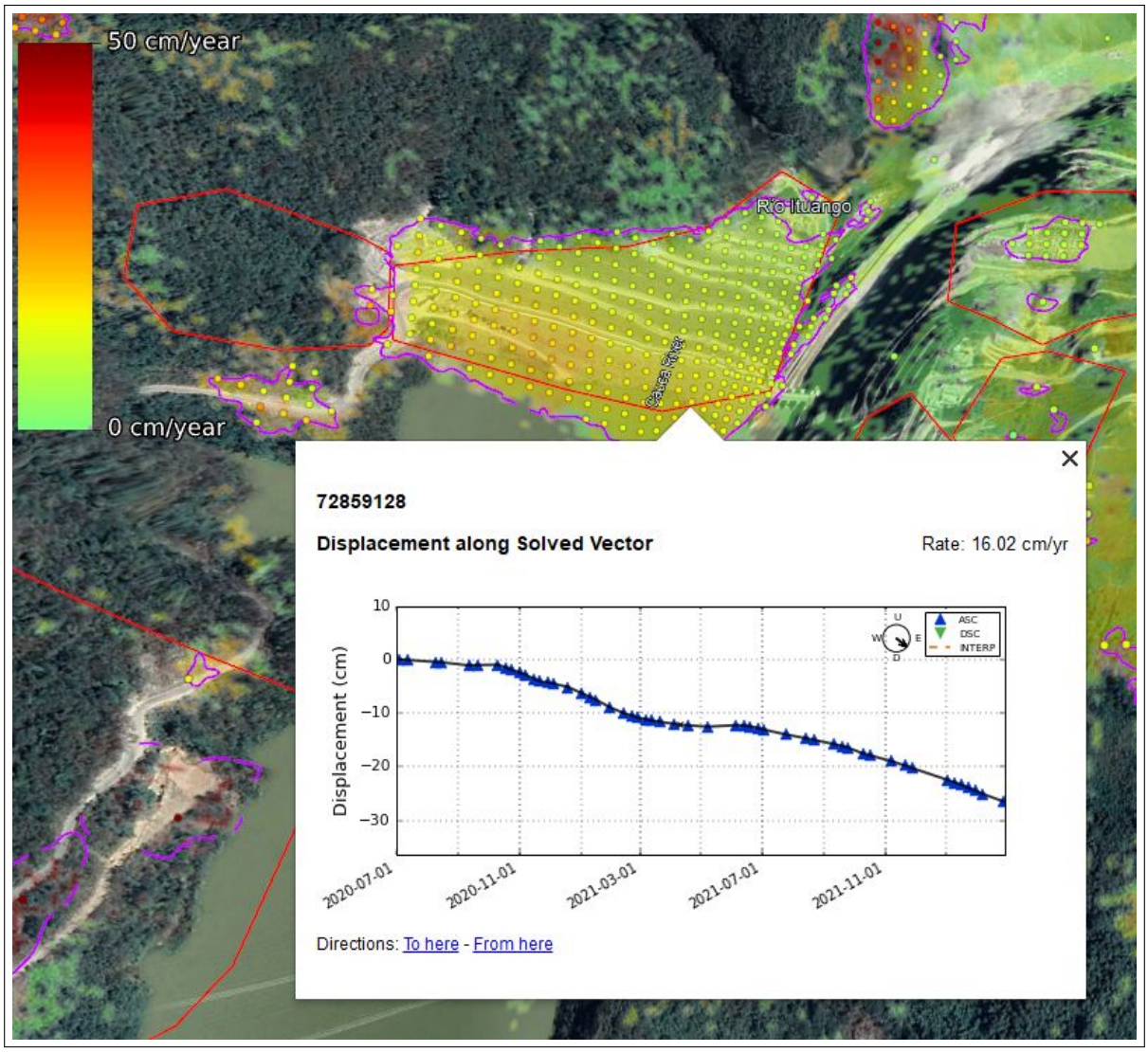


**Figure 5.2:** The displacement rate within the critical area of DAM. This area appears to be moving at an average displacement rate of 16 cm/yr for the last 18 months.

### April 2019 Landslide Helipad

HELIPUERTO

Displacement in the "April 2019 Landslide Helipad" critical area of interest continued growing until November 2021 and started slowing down since November 2021 (Figure 5.3). The time series of a point in the area shows downwards displacement rate reaching 37.28 cm/yr downwards, towards the river.

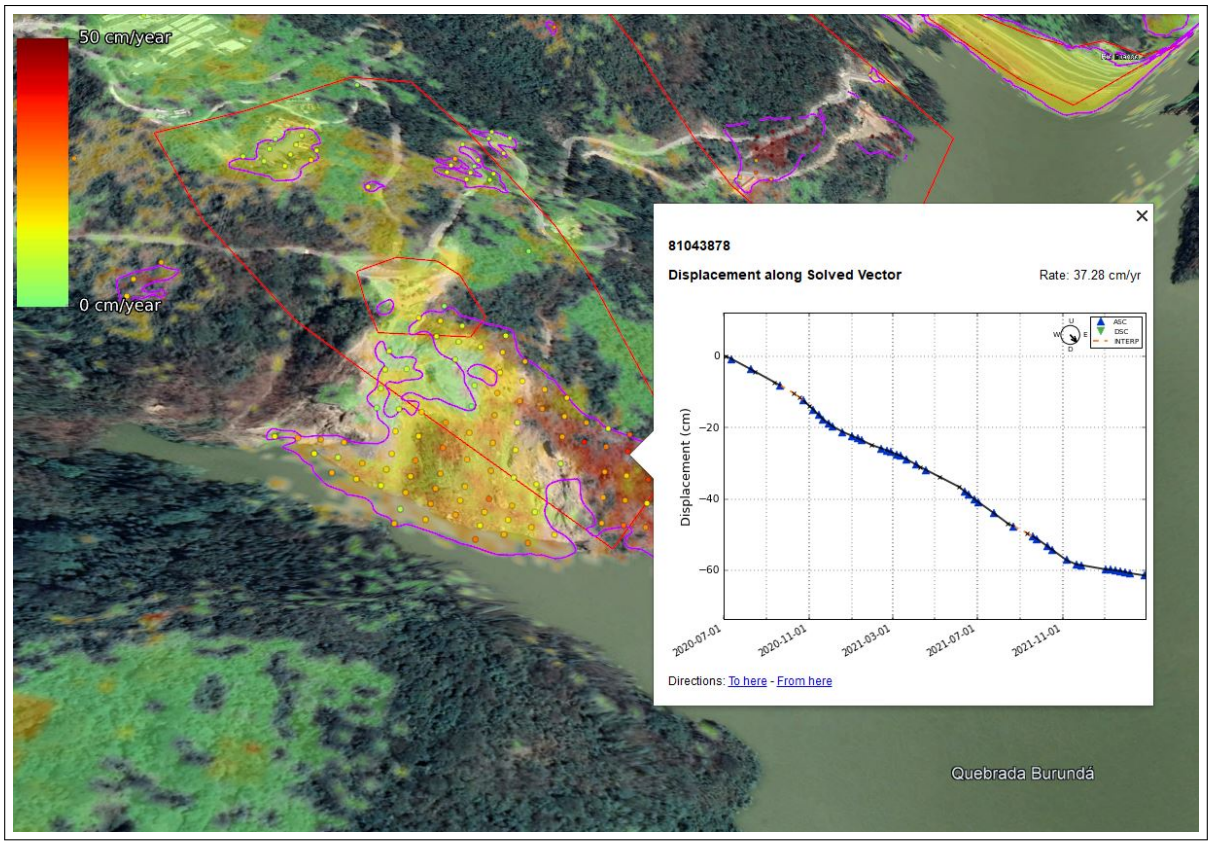


**Figure 5.3:** The displacement rate within April 2019 Landslide Helipad critical area of interest. This area appears to be moving at displacement rates reaching 60 cm/yr.

**Sust Pre Lut**

Figure 5.4 shows the displacement rate over the Sust Pre Lut critical area of interest. Displacement in this area continues growing since July 2020. Although the displacement coverage have been reduced between March 2021 and November 2021 but it came back after that. The time series of a point within the area shows that the area is moving downwards at a displacement rate approximately 65.92 cm/yr.

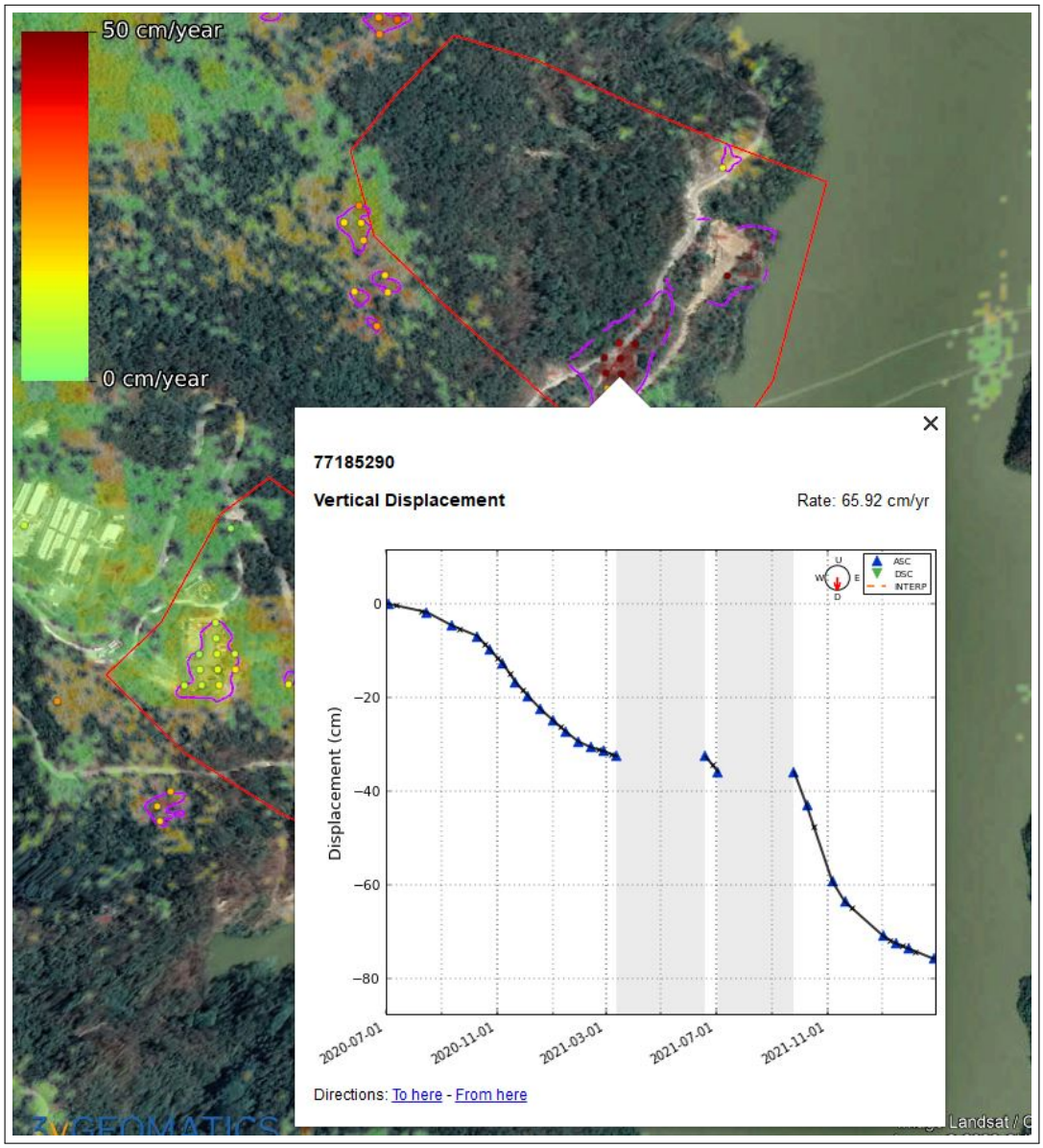


**Figure 5.4:** The displacement rate within Sust Pre Lut critical area of interest.

### Displacement area in sector SSEE

Significant displacement detected in the SSEE critical area still present in the current report. Figure 5.5 shows the displacement rate and time series of a point over that critical area of interest. The time series reveals that downwards displacement had slowed down around March 2021 and started picking up again after July 2021. The displacement rate average for this point was 7.16 cm/yr.

The power-lines and other metallic infrastructure may cause artifacts in the signal; additionally, the good reflective properties can create a bias in signal quality and noise analysis. This area should be interpreted with care regarding displacement direction and magnitude.

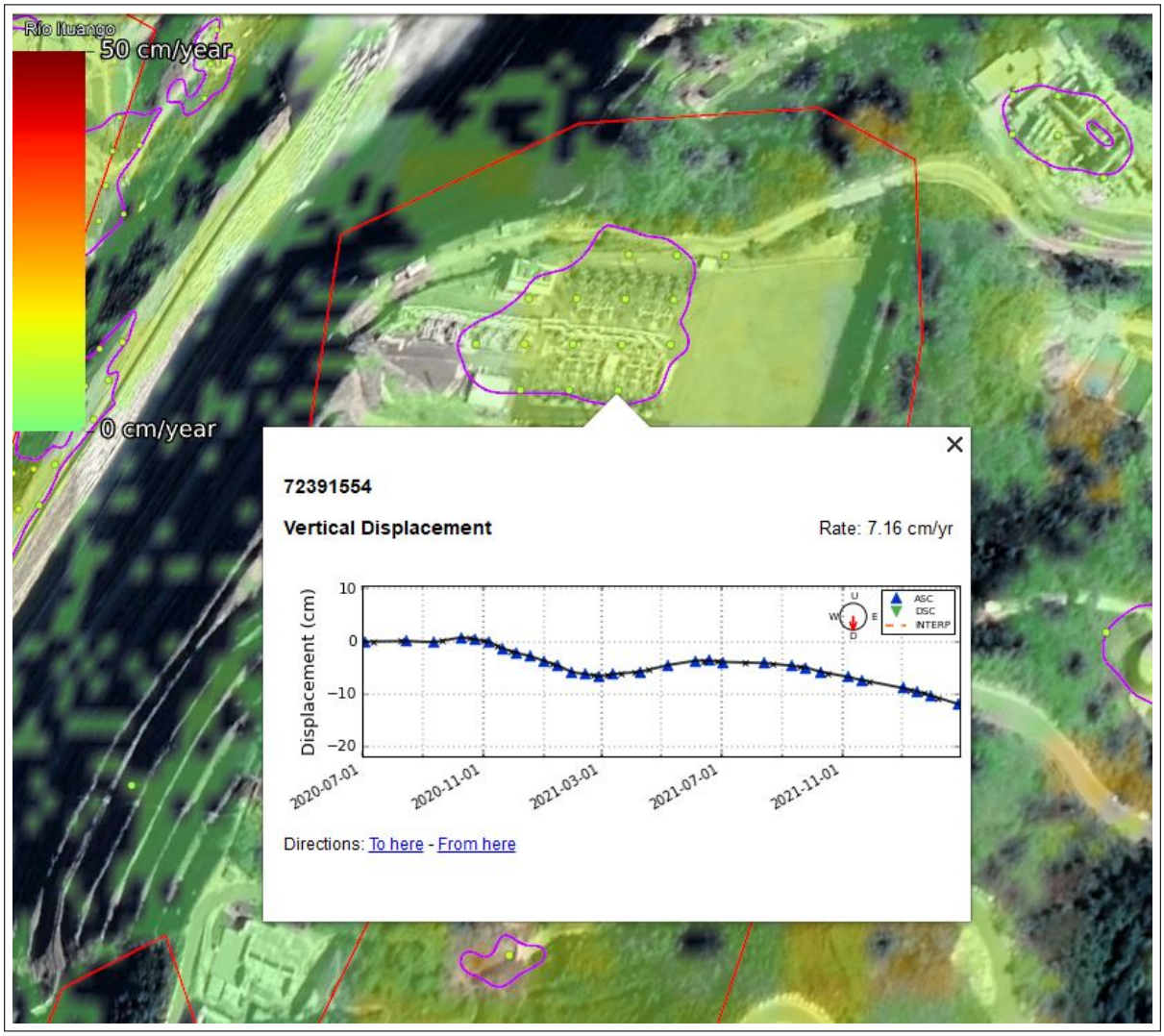


**Figure 5.5:** The displacement rate within SSEE critical area of interest.

### Displacement areas downstream of the dam

Along the main access road downstream of the dam in the Cauca river valley, several landslides are visible on both sides of the valley. Figure 5.6 provides an overview map in Google Earth of three major landslides and for each an example of displacement time series. One notable observation is that for all cases the displacement has slowed down after November 2021.

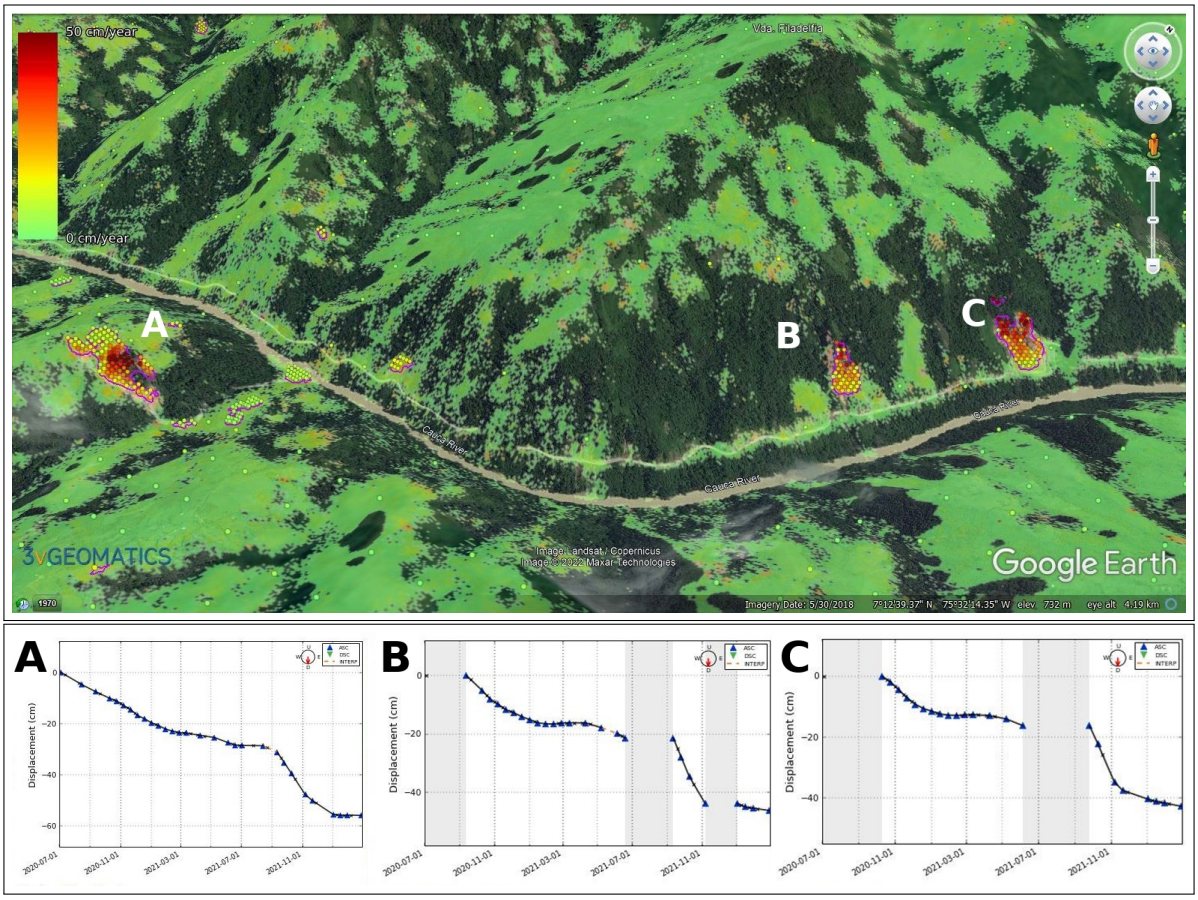


**Figure 5.6:** Overview map of landslides along the Cauca River Valley with the corresponding displacement time series in the bottom row.

# 6 Summary

This Comprehensive Report includes the results of an advanced InSAR analysis of the recent ALOS-2 data ascending SAR imagery available over Ituango Dam and reservoir. The long-wavelength ALOS-2 data offers an effective and economical way to monitor displacement over large vegetated areas of this dam and reservoir. The SNR contours identified several areas of high confidence displacement throughout the footprints, with many falling within the critical areas of interest provided by Integral. Time series displacement graphs were presented for millions of measurement points. 3vG will continue to assess the processing chain in order improve data quality and coverage.

3vG welcomes feedback on any aspect of these products and their usability, including field inspection details.