RÉPUBLIQUE FRANÇAISE
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MAGMATIC SOURCE MODELING AT THE COLOMBIAN ANDES STRATOVOLCANOES REVEALED BY GROUND-BASED AND SATELLITE GEODETIC DATA

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1. INTRODUCTION

1.1. Study region and volcano features

Volcanism in Colombia is driven primarily by the subduction of the Nazca plate (NZ) beneath the North Andean Block (NAB).

- High conical edifices (>4000 m asl)
- Steep topography
- Snow-capped summits
- Dense vegetation
- Strong climatic disturbances

Nevado del Ruiz, Puracé and Galeras are among the most active volcanoes with a long record of eruptions. The eruptions of Puracé in 1949, Nevado del Ruiz in 1985 (~25,000 casualties), and Galeras in 1993, remain among the deadliest disasters in the country.

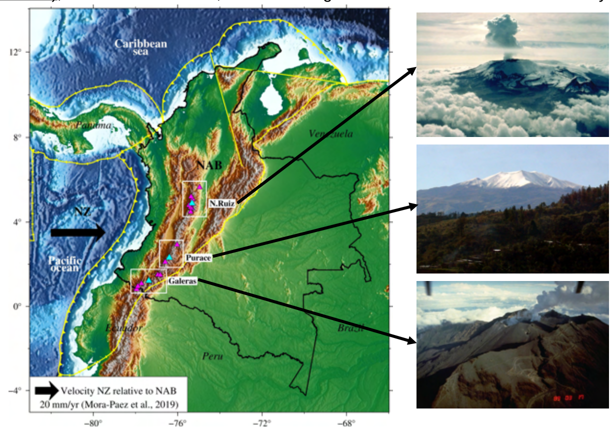


Fig 1. Colombia's tectonic and volcanic setting. Magenta triangles represent the volcanic arc. Studied volcanoes are shown in cyan: Nevado del Ruiz (north), Puracé (center) and Galeras (south). Volcanoes' photos taken from the Global Volcanism Program website.

1.2. Deformation monitoring and challenges

Volcano deformation relates to the storage or movement of fluids inside magmatic or hydrothermal reservoirs that might be linked to potential eruptions.
→ GPS and tiltmeters* and C-band SAR images (Sentinel).
(*installed and maintained by the volcanological observatories of the Servicio Geológico Colombiano)

CHALLENGES	POTENTIAL SOLUTIONS
• Limited resolution of displacement maps due to sparse instrumental networks.	• Continuous displacement maps by using satellite imagery SAR.
• C-band data is affected by vegetation (Sentinel mission).	• L-band data is **less** affected by vegetation **(ALOS mission)**.
• Large tropospheric noise due to strong weather fluctuations.	• Implementation of weather corrections with external datasets **(GACOS and GPS).**

1.3. Objectives

- To estimate accurate maps of displacement from satellite geodetic data.
- To perform precise models of each volcano's internal deformation source responsible of surface displacements (magmatic or hydrothermal).

2. DATA & METHODS

2.1. Data: 100 ALOS-2 images period 2014-2023 in ascending and descending orbits.

2.2. Methods

2.2.1. InSAR technique

Interferogram: Interference pattern between 2 images of the same region at different times → Time series.

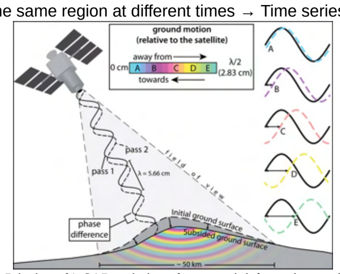


Fig 3. Principe of InSAR technique for ground deformation analysis. Taken from: http://insar.space/insar-technology/

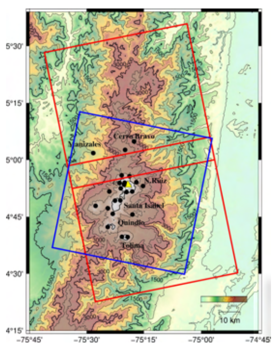


Fig 2. Nevado del Ruiz ALOS-2 footprints in ascending (red) and descending (blue) orbits. GPS stations are denoted by black dots.

2.2.2.Tropospheric noise corrections

- Based on elevation and phase linear correlation.
- Based on ZTD* GACOS products (weather models).
- Based on GPS-derived ZTD maps.

*ZTD: Zenith Total Delay.

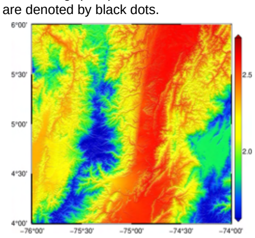


Fig 4. GACOS ZTD map on October 3rd, 2015 at Nevado del Ruiz volcano.

2.2.3.Time series of displacements

Analysis of temporal evolution of surface displacements related to the volcano dynamics.

2.2.4. Modeling

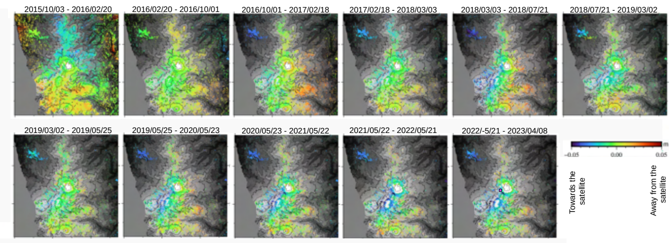
Inversion of InSAR data to define the internal source responsible of the observed surface displacements.
DefVolc (https://doi.org/10.18145/defvolc)

3. PRELIMINARY RESULTS

3.1. Cumulative displacement maps and time series

Nevado del Ruiz volcano

20 sequential interferograms (11 in ascending orbit and 9 in descending orbit).
20 cumulative maps of deformation.



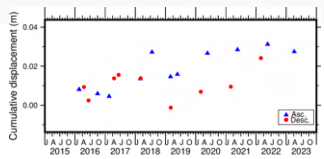


Fig 5. Cumulative maps of displacement in meters at Nevado del Ruiz volcano from October 2015 to April 2023 in ascending orbit. Colder colors indicate the ground is moving towards the satellite, while warmer colors indicate the ground is moving away from the satellite. Left plot represents the time series of displacement of a point indicated by the magenta square on the volcano's summit (last map). Positive trend in both geometries indicates the volcano is inflating.

Puracé volcano

21 sequential interferograms (12 in ascending orbit and 9 in descending orbit).
21 cumulative maps of deformation.

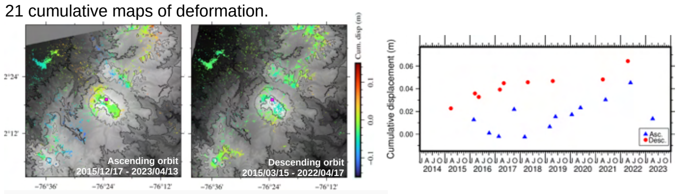


Fig 6. Cumulative maps of displacement in Puracé volcano from December 2015 to April 2023 (ascending orbit) and from March 2015 to April 2022 (descending orbit). Right side plot represents the time series of displacement of a point indicated by the magenta square on the volcano's summit, showing that the volcano is inflating.

Galeras volcano

17 sequential interferograms (9 in ascending orbit and 8 in descending).
17 cumulative maps of deformation.

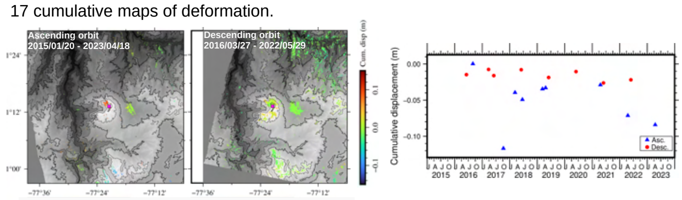


Fig 7. Cumulative maps of displacement in Galeras volcano from January 2015 to April 2023 (ascending orbit) and from March 2016 to May 2022 (descending orbit). Right side plot represents the time series of displacement of a point indicated by the magenta square on the volcano's summit. It shows slow deflation during the analyzed period.

3.2. Preliminary interpretation

Assumption: The motion is mostly vertical because ascending and descending orbits present the same sense of motion for the three volcanoes.

Volcano	Preliminary interpretation
Nevado del Ruiz	Upward trend of time series (Fig 5) could indicate volcano inflation related to magma movement to the surface. **Risk of eruption?**
Puracé	Similar as for Nevado del Ruiz volcano (Fig. 6) **Risk of eruption?**
Galeras	Downward trend of time series (Fig. 7) could indicate volcano deflation. **Risk of collapse of volcano edifice? No risk at all?**

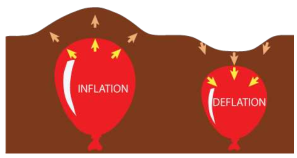


Fig 8. Cartoon representing the ground deformation due to inflation and deflation of a magma chamber beneath it → simple model. (http://www.mshslc.org/activity/volcano-deformation/)

4. FUTURE PERSPECTIVES

Future work will focus on:

- Increasing the redundancy of the time series by computing more interferograms.
- Performing further noise corrections (external data).
- Modeling the deformation signals to characterize the volcano's internal source.
- Publishing scientific papers and presenting at academic meetings.

ACKNOWLEDGMENTS

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