ID: 26

Geodetic monitoring of the dome forming eruption at Nevado del Ruiz (Colombia)

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Nevado del Ruiz volcano (NRV), Colombia, is infamously known for the tragic eruption of November 1985 that destroyed the village of Armero. After a decade of quiescence, the volcano entered a period of renewed activity in 2010 that included a dome forming eruption lasting 4 years (2015–2019). Between 2010 and 2012, the activity encompassed seismic activity and slumping (gravitational spreading) of the volcanic edifice. In March 2012 an inflationary trend started, recorded in tiltmeters, Global Navigation Satellite System (GNSS) stations, and differential radar interferometry (DinSAR), together with a significant increase in seismicity, SO_2 release and ash emissions. Short and sporadic 'drumbeat' seismicity started in August 2015, coinciding with inflation recorded by a large positive surface tilt change, small volcanic explosions, and a dome-forming eruption at the bottom of the main crater. The inflation stopped at the end of 2017, while the dome growth ended in December 2019.

Modeling of the deformation shows the existence of two sources. A shallow source, feeding the ash emissions, gas release, and the dome forming eruption, imaged only in the tilt record, that is located within the volcanic edifice. A deeper source is imaged in both the GNSS and InSAR record. The deeper source is located 7 km southwest of the main crater of NRV, at a depth of 15 km beneath the Nevado of Santa Isabel. Modeling suggests that approximately 0.2 km^3 of new magma/fluids has intruded into this deep reservoir since 2010.

ID: 42

New insights on the 2011-2021 unrest at Long Valley Caldera (USA) from InSAR and GNSS data

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Long Valley Caldera (Eastern California, USA) has experienced seismic swarms and ground deformation since 1979 and has been generally restless over the past several decades, with the last inflation phase starting in late 2011. The primary cause of the inflation is attributed to deep dynamics within the caldera plumbing system. In this study, we investigated the most recent deformation trends using geodetic data spanning 2011 to 2021. We exploited InSAR datasets derived from TerraSAR-X, COSMO-SkyMed and Sentinel-1 missions, and GNSS velocities derived from the available network of continuous stations. A circular deformation pattern was obtained within the caldera that is centered on the caldera's resurgent dome area. This tumescence lasted until 2021, with uplift rates up to ~2 cm/yr in the first four years (2011–2015) but decreasing afterwards to lower velocities. Finally, we modeled the deformation source parameters for two time periods (2011–2014 and 2015–2021), given the different rate of surface deformation. GNSS and InSAR data were weighted in the inversion process. Our preferred models for the deformation source during the two phases are similar, represented by a nearly vertical ellipsoidal chamber, with the centroid shallowing from 7±0.2 km in 2011–2014 to 5±0.4 km depth in 2015–2021. Also, the volume change rate is reduced in the last period, interpreted as a general decrease of the volcanic activity at the caldera.

ID: 105

Lesson learnt from the recent past to understanding the activity of a restless caldera: the case of Campi Flegrei (Italy)

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Calderas are characterized by several volcanic manifestations, seldom followed by eruptions. Therefore, eruption forecast studies are challenging. Campi Flegrei caldera is located 20 km west of Naples (Italy). Its last eruption, that formed the Monte Nuovo scoria cone, took place in 1538. Since then, the caldera was affected by an overall subsidence until the 1950s, interrupted by unrest episodes in the 1970s and in 1982-84, when the ground uplifted 1.5 m in its center (Pozzuoli). Since 2005, the caldera has been in an unrest phase, documented by increasing rates of deformation, seismicity and gas emissions. In this work we consider a unique dataset of elevation variations at 20 sites in the caldera, retrieved from archeological, historical, volcanological and bathymetric data, since 35 b.C., chained to the leveling data from 1905, until 1999. These data are an unparalleled chance to study the evolution of the ground displacement at a caldera with limited eruptive episodes. The deformation sources retrieved from data modeling evidence several similarities with the plumbing system defined by modern InSAR and GNSS data. Indeed, the central shallow source (4-5 km depth below Pozzuoli) plays a key role both during the pre- and post- eruptive phases and the recent unrest episodes. Also, the activity of a deep reservoir at 8 km depth is constrained during both uplift and subsidence phases. Estimates of intruded and erupted volumes in the last centuries suggest a worrisome 100 to 1 ratio, indicating that only a minor part of the intruded magma has been erupted.

ID: 134

Analysis of the lava lake and magma flows during 2023 Nyamulagira volcanic activity detected by SAR coherence variations

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Mount Nyamulagira is an active volcano located in the eastern Democratic Republic of Congo close to the border with Rwanda, and at about 30 Km north of Goma city and lake Kivu. Together with Nyiragongo, they form the Virunga Volcanic chain, one of the most hazardous area of the world due to the intense volcanic activity coupled to the density of inhabitants of the surrounding cities and towns. According to the report of Goma Volcano Observatory (GVO), from February 2023 Nyamulagira has shown an increasing of the volcanic activity characterized by frequent effusive eruptions from the northeastern crater pit and the intermittent presence of a lava lake inside the caldera. In this work, such phenomena have been analyzed using remote sensing Synthetic Aperture Radar (SAR) data acquired from January to June 2023 by Sentinel-1 missions. To follow the temporal evolution of the volcanic activity, a coherence variations analysis was performed to constrain any magma movements inside the crater and lava flows along the flanks of the volcano. Experimental results show a significant magma effusion inside Nyamulagira caldera from the beginning of March, while in mid-May the increasing of the activity induced a magma overflowing the caldera producing a lava flow along the NW flank of the volcano. Then, starting from the end of May-early June, the activity started to return to low levels. These results were synergistically used with other data to support the GVO local monitoring team in the management of the May 2023 Nyamulagira volcanic crisis.

ID: 146

Unrest Dynamics of Domuyo Volcano, Argentina: Magma influx coupled with gas diffusion as a mechanism to explain geodetic and thermal time series

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Domuyo volcano is a large silicic system that has experienced a cycle lasting more than a decade of deflation-inflation-deflation, with a low-temperature thermal anomaly showing a similar but lagged cooling-warming time series. We present a fluid-mechanical magma reservoir coupled with Darcy flow of volatiles through the crust to model the observed geodetic and thermal time series. Domuyo is a large (4700 m high) volcano with the second largest hydrothermal system in the world, despite its most recent effusive eruption dating to ~100,000 years before present. InSAR time series from several satellites (ALOS, RADARSAT-2, ALOS-2, and Sentinel-1) shows deflation (2008-2013), pause (2013-2014.5), then rapid inflation, up to ~70 cm in the radar line-of-sight (LOS) through 2020, that is now deflating. During the period of rapid inflation, seismicity also showed a commensurate increase. Low-temperature thermal anomaly time series from MODIS data appears lagged with respect to the InSAR time series (through 2023), suggesting a bottom-up model driven by magma influx. To test this conceptual model, we have developed a thermo-fluid-mechanical model using COMSOL Multiphysics. This model features periodic pulses of magma influx into a geodetically constrained flat ellipsoidal source centered at 6.5 km depth coupled with Darcy flow of hot CO_2 through the crust. The amplitudes and lag times of inflation-deflation and thermal time series are roughly fit by this model, suggesting that the mechanism proposed might control Domuyo's dynamics. Similar mechanisms might be responsible for the so-called caldera breathing at systems like Long Valley, Laguna del Maule, and Campi Flegrei.

ID: 259

What can we learn from the 2021 paroxysmal activity of Mount Etna? An InSAR and GNSS Ground Deformation Analysis

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Mount Etna is surrounded by increasingly dense populated areas. Its volcanic hazards include among others lava flows, earthquakes and tephra falls. In the most recent years, Etna volcano has experienced strong activity characterized mainly by continuous degassing and recurrent lava fountains. Ground- and space-based systems are routinely used for monitoring the ground deformation.

In December 2020, a period of paroxysms with powerful, brief bursts of lava fountaining began, which intensified in February 2021 and lasted until April. By constraining the sources of the observed paroxysms, this study aims to understand the dynamics and structure of the feeding system. We used Sentinel-1 SAR images along with GNSS permanent network data to examine the deformation at Mount Etna in order to locate and characterize the time-dependent ground deformation sources. We have applied the SISTEM algorithm, which allows to estimate 3D ground displacements by combining GNSS displacements and Differential Interferometric Synthetic Aperture Radar (DInSAR) displacement maps. According to the DInSAR and GNSS time series, the deformation pattern registered during the first half of 2021 was mainly characterized by a deflation period, suggesting a link with the volcanic activity.

The findings of this work serve to further the discussions on 1) the distribution and dynamics of the magma reservoir that shape the conduit system of Mount Etna and how those reservoirs interact with the regional tectonic regime and 2) the complexity of the deformation signals and how to deal with their different contributions including volcanic-, tectonic- and geomorphological processes, as well as atmospheric noise.

ID: 297

Is the recent uplift episode at Askja Volcano (Iceland) something to worry about?

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Monitoring Askja Volcano is vital to forecast eruptions and ultimately to reduce the risk to human life. High-velocity uplift began in the centre of the caldera in the summer of 2021, following a period of long-term subsidence that started before 1983. The uplift reached velocities over 700 mm/yr at Global Navigation Satellite System (GNSS) station OLAC during the first two months and then decreased to ~280 mm/yr. As of September 2023, the uplift at this site had reached ~650 mm[SE1] . To understand the implications of this uplift we need to know whether this was produced by a new input of magma and whether that intrusion continued until September 2023. An alternative hypothesis is that the initial uplift was due to the migration of existing magma within the system to a higher level, and subsequent inflation is, in part, due to post-intrusion relaxation. Answering these questions is important for determining the most likely scenarios for possible new eruptions.

To address these questions, we use Synthetic Aperture Radar Interferometry data acquired from Sentinel-1 between 2015 and 2023. We have analysed SAR data from four tracks and referenced the velocities to GNSS data. We complement the results with gravity data collected every year since 2021 to determine if there is a new input of magma. Finally, we have built a poro-viscoelastic model using finite elements to explore two scenarios: i) an initial migration of magma and its post-intrusion relaxation, and ii) continuous input of magma, but with a change in the flux.

ID: 353

Fifteen years (2008-2023) of geodetic observations at Shishaldin Volcano, Alaska, USA

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Shishaldin Volcano, a symmetrical cone covered by snow and ice, is one of the most active volcanoes in Alaska. At least 26 eruption episodes have been confirmed in the last 300 years. We process geodetic data from 2008-2023 but neither InSAR nor GNSS measurements show noticeable eruptive deformation. This suggests that any potential pre-eruptive pressure buildup either occurs shallow within the edifice and surface deformation is obscured by snow and ice, or magma reservoir pressure is hydrostatically compensated through magma head changes in the conduit system. Based on the eruptive behavior, we hypothesize a vertical magma conduit system and analyze 15 years of tilt records in order to characterize an open conduit. Our focus centers on the most recent eruptive episodes 2014-2016, 2019-2020, and 2023 (ongoing as of this writing). Data sources encompass continuous tiltmeters and tilt derived from broadband seismometers. We eliminate tidal motion from the time series and filter out high frequencies from the remaining signal to remove co-eruptive dynamic deformation. Among other events, our study highlights a lava drainage event, captured by AV37, a tilt station 5 km south of the crater where the station exhibited an inclination of 400 nrad in the radial direction. The event was not detected by AV36, a station 10 km west from the crater. We invert these two observations using an open conduit model. The results suggest a 3 km long conduit with a radius of ~80m. We contrast these measurements with the quantification of morphology changes using SAR amplitude images.

ID: 360

Towards a global understanding of the processes governing volcanic deformation

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Episodes of volcanic uplift have been observed all over the world and have been identified as potential precursors of volcanic eruptions, as they have classically been interpreted as the result of magma coming to the surface. However, this assumption has recently been questioned with the observation of calderas deforming metrically for several decades without erupting. Currently, the processes that produce these uplift episodes are not clear and the classical models used to interpret them are being questioned, as they do not represent the expected mechanical behaviour of the deep volcanic system. Here, we compiled time series of several volcanoes, calculated using InSAR, GNSS and Tilt techniques. We focus our analysis on volcanoes that have experienced one or more periods of uplift, some, but not all followed by eruption. By normalising these uplift episodes in time and magnitude, we found that deformation follows a common pattern for all of them after some time, regardless of their location or composition, suggesting a common mechanism. To determine whether it is the crust, the existing reservoir and/or the magma injection itself that causes this common transient deformation, we use analytical models that incorporate elasticity, viscoelasticity and poroviscoelasticity. Our results suggest that the uplift episodes are initially generated by magma injections, but then it is the poroviscoelastic response of the existing reservoir that generates this common transient evolution. These results highlight the importance of considering rheological heterogeneities in future models to advance in predicting volcanic behaviour.

ID: 433

The 2021 Resurgence in Deformation at the Three Sisters Volcanic Field, Oregon Cascades

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This presentation seeks to explore the significance of possible aseismic volcanic inflation and unrest while contributing to the understanding of mid-crust magma storage beneath the Three Sisters. We analyze Sentinel-1 InSAR data from 2019 to 2023 to quantify the most recent uplift at Three Sisters Volcanic Field, Oregon. We find that 1.5 to 2 cm of uplift occurred between June 2020 and September 2021 through an analysis of seven descending and four ascending SAR time series. The Three Sisters uplift is occurring near central Oregon in a volcanic field that consists of 460 vents of Quaternary age. The area of interest, situated 6 km west of the South Sister volcano, began uplifting in 1998 with an increasing uplift rate that peaked at 3-5 cm/yr in 2001, and over two decades slowly decayed below the signal-to-noise ratio of SAR observations. On January 31, 2022, the U.S. Geological Survey reported that uplift had renewed. Utilizing the InSAR time series and continuous GPS station data we were able to identify when this most recent intrusion event occurred. Furthermore, we modeled the depth and size of the new intrusion and statistically compare the source location to earlier periods. We also compared the deformation characteristics from the Three Sisters uplift to volcanoes in Alaska (Westdahl and Peulik) that have experienced aseismic magma transport and uplift to determine how unique the conditions are at the Three Sisters.

ID: 455

Noise or Signal? A Holistic Approach to GNSS-Based Volcanic Hazard Monitoring

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It is well established that explosive volcanoes pose a significant threat to adjacent communities. Despite the risks, stratovolcanoes are the backdrop for many societies across the globe. A number of tools exist by which to monitor primary and secondary hazards, but system errors and remote locations frequently create monitoring challenges that demand comprehensive solutions. These shortcomings highlight the need for enhancing geodetic real-time hazard monitoring systems for volcanic regions.

We present two emerging GNSS-derived methods that leverage atmospheric noise otherwise removed during traditional monitoring efforts. First, we discuss the potential for detecting volcanic tsunamis in the ionosphere - a layer of Earth's upper atmosphere - to complement existing in-situ ocean buoy alert systems. While this task has been performed in a number of isolated studies, including our own work on the 2022 Tonga eruption, a global effort is underway to develop this technique into a real-time operational system. Second, we explore the possibility of improving deformation data by resolving anomalies in tropospheric wet delay, measured in Earth's lower atmosphere. Deviations in wet delay observed through the Tonga eruption plume suggest that temperature/pressure assumptions are incorrect in current troposphere models. As these models are used to resolve tropospheric noise in GNSS-based deformation monitoring, we assume that deformation data is negatively impacted by these anomalies.

This research holds promise in particular for remote or developing regions, as these analyses are inexpensive to perform, utilize existing GNSS networks, and don't require physical access to the volcano.

ID: 639

Unveiling Surface Deformation Patterns at Rincón de la Vieja Volcano: A Geodetic Study

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Rincón de la Vieja Volcano, located in the Guanacaste Volcanic Cordillera, has not yet been meticulously studied for surface deformation using InSAR. This study focused on the period between 2020 and May 2023 using ascending and descending lines of sight of the Sentinel-1 satellite, capturing a comprehensive picture of the volcano's behaviour.

The southwestern flank of the volcano remained remarkably stable throughout this study period, suggesting minimal surface changes associated with recorded volcanic events. Intriguingly, the Volcano's Summit and the nearby Cerro Góngora displayed a dynamic behaviour. Surface displacement in these areas exhibited a reversal in direction during the periods from January 2020 to April 2021 and from January 2022 to June 2023. The most plausible interpretation is a combination of subsidence and a northwestward movement. The significance of these findings lies in the potential implications for volcanic risk management in the region.

Understanding the complexities of such deformation patterns is pivotal for volcanic risk assessment and management. We continue with further investigation, utilizing high-resolution satellite imagery and seismology to precisely delineate the extent of subsidence and gain deeper insights into the geological and geodynamic processes driving these phenomena.

This study provides crucial insights for predicting future volcanic eruptions and managing the risks associated with this volcanic system. The results underscore the necessity of adopting a multidisciplinary approach that incorporates geodetic monitoring, geological surveys, and geophysical modelling to comprehensively evaluate volcanic hazards in urban areas near the volcano.

ID: 679

What does ground deformation and brittle fracture earthquake swarms at long-dormant Chiles-Potrerillos volcanoes, Ecuadorian-Colombia border, reveal about potential crustal failure?

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Long-dormant volcanoes often display extended reactivation periods before magma ruptures the crust and erupts. A repetitive pattern of local VT swarms with ground deformation, especially if it´s exponential, may be a proxy for the progressive stretching of an elastic-brittle crust until failure. We explore the case of two dormant volcanoes sharing VT swarms (about a million cumulative events) and simultaneous uplift. We also evaluate the crustal deformation regimes during five swarm/deformation episodes from 2014 to the present.

In 2014, a binational geophysical network around Chiles volcano, Colombian-Ecuadorian border, detected sudden seismic (5000 events/day) and crustal unrest. Other reactivations followed in 2018-2019, 2020-21, and later, in May 2022, two seismic swarms broke out. The first swarm´s epicenters were located on Chiles´ S flank; automatic counts yielded peaks of 4000 earthquakes/day between May and December 2022. Simultaneously, about 1500 earthquakes were located at depths 2 – 15 km bsl on the Potrerillos plateau, 15 km SE of Chiles. Beginning abruptly on 09 March 2023, the most recent swarm produced 4300 VT events/day.

Contemporaneously, displacements of GNSS stations' vertical and north components showed offsets to the SW and ~10 cm/yr uplift. InSAR data also reveals deformation hotspots at Chiles´ S flank and on Potrerillos plateau.

Modeling GNSS and InSAR data shows that deformation could be consistent with dike intrusion, but seismic depths aren´t shallowing or have alignments that mirror dike emplacement. Alternatively, the VT swarms suggest that elastic-brittle failure of the crust could favor precursory phreatic explosions before the rupture of crustal seals.

ID: 725

Estudio de procesos de inflación en los volcanes del Sur del Perú: casos de Deformación continua, Pre-eruptiva y sin Erupción

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Este estudio analiza los fenómenos de deformación relacionados con erupciones y no erupciones en tres volcanes ubicados al sur del Perú: Sabancaya, Ubinas y el Complejo Volcánico Casiri.

Sabancaya inició su proceso eruptivo en noviembre de 2016, que continúa activo hasta la fecha. Se ha observado un constante proceso de inflación, con una tasa de 50 mm/año desde 2013, evidenciado mediante datos GNSS e imágenes de radar Sentinel-1. Esta inflación se asocia a un reservorio de magma profundo situado 5 km al norte y a 12 km de profundidad.

Ubinas comenzó su último proceso eruptivo en julio de 2023. Más de dos meses antes del inicio de esta erupción, se detectó un proceso inflacionario de 53 mm/año, que solo se evidenció a través de los datos GNSS y no con imágenes SAR. Este proceso se vincula a un reservorio de magma superficial ubicado a 1.5 km al oeste del cráter y a 7 km de profundidad.

A pesar de no haber experimentado erupciones, el Complejo Volcánico Casiri mostró un claro proceso de inflación entre agosto de 2019 y noviembre de 2021, con una tasa de 57 mm/año. Este fenómeno se identificó mediante imágenes de radar Sentinel-1 y parcialmente con datos GNSS. Esta inflación se relaciona con un reservorio de magma profundo ubicado a 5 km al noroeste y a 10 km de profundidad.

ID: 136

Evolution of the shallow reservoir at Campi Flegrei caldera (Italy) during the 2007-2020 unrest

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Multi-technique geodetic data (satellite, inland and seafloor GNSS measurements) are collected to study the recent unrest at Campi Flegrei Caldera (Italy) from 2007 to 2020, where increasing seismicity, gas emission and ground deformation have been observed. To understand the evolution of the unrest, 3D finite element models are employed in a Bayesian inversion framework, including the elastic heterogeneous structure of the underlying medium based on the newest seismic tomography of the area. The analysis divides the whole period into five distinct time intervals, guided by changes in ground displacement time series, as derived from geodetic data. The modeling approach implements a double-source plumbing system: a central shallow source with its depth and geometry to be determined by the inversion process, and a second deep tabular source fixed at 8 km depth, consistent with the petrological and geochemical evidence of melt and massive degassing from the deepest portion of the magmatic system. The results reveal that the central source beneath Pozzuoli exhibits a gradual shallowing, from 5.9 km depth during 2007-2010 to 3.9 km during 2017-2020. The outlined dynamics take place below the seismicity swarms, which are shallower than 3 km depth. Concurrently, the deep tabular source at 8 km depth experiences a constant but limited deflation over time. The depicted plumbing system evidences a sequential growth of horizontal opening and volumetric expansion of the central source, likely accommodating magmatic fluids from the deep source for 13 years at least, for a total volume variation of about 60 million m^3.

ID: 80

Complex magma propagation paths during the 2017, 2018 and 2020 eruptions at Fernandina (Galápagos) inferred from InSAR data and geodetic modelling.

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Previous work at Fernandina (Galápagos) revealed evidence for both a shallow and a deep magma reservoir, but the relative contribution of the two reservoirs to eruptions remains unclear. Furthermore, Fernandina shows complex magma propagation paths during eruptions that can significantly change from one eruption to another. Here we investigated with InSAR data and geodetic modelling deformations occurred from 2017 to 2020. Our results highlight how the 2017 eruption magma was due to a circumferential dike fed by the deep reservoir. Two episodes of new magma inflow occurred in both reservoirs from December 2017 to May 2018. During the 2018 eruption, both reservoirs fed two radial feeder dikes below the north flank, probably interacting with an underlying peripheral melt pocket, and an inclined sheet below the NW sector of the caldera that remained intruded. Both magma reservoirs experience a new inflow of magma from July 2018 to January 2020. During the January 2020 eruption, a radial dike propagated southward changing its geometry at each topographic change. No deformation matches in location with the eruptive fissures, likely associated with an ephemeral circumferential dike that have shared with the radial dike the same intra-caldera intruded sill. Our results highlight the primary role of the deeper reservoir that accumulates most of the magma before eruptions. Furthermore, the 2018 and the 2020 eruptions show how eruptions at Fernandina can involve multiple sills and dikes that propagate in multiple directions with different geometries and that potentially might trigger simultaneous eruptions in different locations in the future.

ID: 106

Volcanic and Seismic source Modelling (VSM) - An open tool for geodetic data modelling

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Volcanic and Seismic source Modelling (VSM) is an open-source Python tool to model ground deformation detected by satellite and terrestrial geodetic techniques. It allows the user to choose one or more geometrical sources as forward model among sphere, spheroid, ellipsoid, fault, and sill. It supports geodetic from several techniques: interferometric SAR, GNSS, levelling, Electro-optical Distance Measuring, tiltmeters and strainmeters. Two sampling algorithms are available, one is a global optimization algorithm based on the Voronoi cells and the second follows a probabilistic approach to parameters estimation based on the Bayes theorem. VSM can be executed as Python script, in Jupyter Notebook environments or by its Graphical User Interface. Its broad applications range from high level research to teaching, from single studies to near real-time hazard estimates. Potential users range from early career scientists to experts. It is freely available on GitHub (https://github.com/EliTras/VSM). In this contribution I show the functionalities of VSM and test cases.

ID: 142

Analysis of the recent Copahue Volcano unrest (2015-2023) from geodetic data

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Copahue volcano has been experiencing continuous unrest since December 2012, when a strombolian eruption released a plume reaching a height of 1.5 kilometers from its summit crater. This volcano is located in the southern Andes of South America, on the border between Argentina and Chile (37°51'S-71°05' W) located less than 10 kilometers away from the popular tourist villages of Caviahue and Copahue. These villages attract thousands of visitors each year during peak season. The ongoing unrest is characterized by ground motions and seismicity accompanied by emissions of ash, incandescent material, and high levels of SO2 emissions.

This study focuses on the ground motion observed in two geodetic data sets, Sentinel-1 SAR and GNSS, collected between 2015 and 2023. Over this time frame, a recurring pattern emerges, characterized by an uplift phase followed by subsidence, which repeats twice. However, this cyclic process has only managed to recover half or less of the total vertical displacement observed so far. Preliminary results from geodetic inversion models during the ongoing subsidence phase indicate the presence of a contracting sill-type source situated at a depth of 8.5 kilometers. This deep source coincides with the deepest segment of a complex plumbing system inferred by previous studies from seismicity analysis and inversion models at the onset of the unrest.

ID: 177

Modelling Surface Deformation due to Magma Migration through Mush Zones

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Ground deformation at volcanoes is key for interpreting the processes occurring in the system below. Studying the spatial and temporal evolution of surface patterns can help us to characterize the geometry of the deformation source, as well as to track magma migration. Most models used to interpret deformation assume either a purely elastic rheology, a spherical reservoir, or more complex rheological properties but limited to a reservoir shell. However, this is inconsistent with the most widely accepted conceptual model of magmatic plumbing, the Trans-Crustal-Magmatic-System (TCMS). The TCMS model contains a widely heterogeneous thermal system, primarily comprised of magma mush: a porous crystalline matrix saturated with interstitial viscous melt and fluids. How these different fluids interact in the system and how this affects surface deformation is not yet clear. Previous models have shown that incorporating mush can both augment and depress the magnitude of deformation, potentially disrupting accurate forecasting.

Using numerical models, here we simulate the mechanical complexity of the TCMS by introducing poro- and visco-elastic rheologies, which both contribute a time-dependent distortion to deformation upon perturbation of the system. Particularly, we investigate how the position of a melt lens within a vertically elongated mush can impact the development of geodetic signals, and how this in turn is affected by the mush viscosity. As the resolution of geodetic monitoring increases, so does the importance of incorporating mush properties into volcano deformation interpretation. This is critical for identifying new intrusions of magma, assessing their volume and aiding migration forecasting and hazard management.

ID: 291

Finite element modelling of the source of ground deformation in Tenerife (Canary Islands) during the 2004-2005 unrest

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Historic volcanic activity in Tenerife was concentrated within two of the island's three dorsals, primarily characterized by basaltic fissural eruptions. Conversely, the central Las Cañadas caldera and the Teide-Pico Viejo complex, located inside it, included phonolitic eruptions, occasionally interspersed with basaltic and trachybasaltic materials.

Our study focused on investigating the deformation that occurred during the 2004-2005 interval, coinciding with heightened seismic activity on the island, changes in the chemical composition of fumaroles of the Teide composite volcano, an increase in diffusive emissions of carbon dioxide along the NW rift, and, significant gravity changes.

To characterize the source of ground deformation, we used the Envisat-ASAR dataset spanning from 2003 to 2011 to generate a DInSAR SBAS deformation time series of the island. Applying Independent Component Analysis (ICA) to this dataset allowed us to separate distinct deformation patterns. The first pattern mainly affects the Teide stratovolcano's southern part, exhibiting an east-west orientation. We also identified another deformation pattern in the summit region of Teide with a circular symmetry. The latter is likely to be related to residual topographic effects.

To determine the geometry of the source responsible for the main deformation of the volcano's southern side, we used a non-linear optimization approach, using a generic 3D ellipsoidal geometry for modelling the source through Finite Element Modelling. The results revealed that the reactivation of the hydrothermal zone beneath the Teide volcano is the most likely source for the observed deformation.

ID: 313

Towards a systematic catalogue of volcano deformation source parameters from Sentinel-1 InSAR data

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Understanding the global patterns and spatio-temporal characteristics of volcanic deformation is important for improved eruption forecasting through identifying analogue behaviours and commonalities between volcanoes. Previous metadata catalogues are incomplete and biased by methodological differences in data and modelling. However, the large archive of systematically acquired and processed Sentinel-1 data now provides the opportunity to overcome these limitations and construct the first systematic volcano deformation catalogues.

Here, we systematically extract deformation characteristics from Sentinel-1 InSAR datacubes, focusing on source parameters extracted through inversion modelling. We adapt GBIS, a Bayesian non-linear inversion software, to run in an automated fashion. We use synthetic examples to explore pre-processing options, focussing on downsampling, initial model geometry, and bounding boxes. We first apply a Mogi model to all the signals and then try alternate source geometries, comparing the improvements in fit using Akaike's Information Criterion.

We test our approach using Sentinel-1 datacubes from the East African Rift where 14 volcanoes show deformation. GBIS inverts for the target signal location (lat/lon coordinates) at 12/14 volcanoes: 9 signals are fit with a Mogi or sill-like source, and an additional 2 can be fit by an Okada source, with the output parameters falling within the ranges of previous modelling studies. Complications arise when there are multiple signals per interferogram. We combine the extracted source parameters with those describing their temporal behaviour to produce a regional catalogue. This approach has the potential to be applied globally to produce a systematic volcano deformation catalogue which can be used for eruption forecasting.

ID: 371

Joint exploitation of geodetic and seismic data to detect hydrothermal unrest in active calderas: A case study of the 2021-23 Vulcano Island (Italy) crisis.

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Active calderas are commonly distinguished by superficial magmatic systems linked to pronounced geothermal abnormalities and substantial fluid emissions. The La Fossa caldera, situated on Vulcano Island within the Aeolian archipelago (Italy) is an caldera exhibiting extensive degassing and fumarolic activities. Since September 2021 the La Fossa caldera has displayed indications of increased activity, and as of the present, monitoring parameters have yet to revert to their baseline levels.

Hence, geophysical measurements acquired from the monitoring infrastructure on Vulcano Island were subjected to analysis. This infrastructure encompasses geodetic and seismic data. GNSS and DInSAR data were utilized. GNSS data were processed using the GAMIT-GLOBK software to compute time series and velocities for each remote station within the 7-station network covering Vulcano and Lipari islands. Meanwhile, DInSAR data were processed utilizing the P-SBAS technique to pinpoint the source of deformation. The seismic network data were leveraged to differentiate seismic events resulting from regional tectonic forces from those triggered by magmatic or hydrothermal activities, such as VT, VLP, and seismic tremor.

The inversion of ground deformation measurements facilitated the examination of the source within the hydrothermal system of the La Fossa Caldera. the analysis of seismic data disclosed the activation of regional crustal structures during the period of hydrothermal unrest, along with the circulation of hydrothermal fluids within the caldera structures, which is associated with the existence of a pressurized hydrothermal system. The presented results provide a overview of the main findings relevant to the Vulcano Island geodetic and seismic data inversion analysis.

ID: 395

Estudio preliminar de los desplazamientos superficiales del Popocatépetl por medio de InSAR

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El análisis de la deformación es esencial para comprender los diferentes procesos asociados con la actividad volcánica. La interferometría SAR (InSAR) puede coadyuvar a cuantificarla de manera espacial y temporal. No obstante, los estratovolcanes presentan desafíos particulares debido a la alta decorrelación en la fase interferométrica. Para abordar estos desafíos, se utilizan metodologías multitemporales, como Líneas de Base Cortas (SBAS) y Dispersión Persistente (PSI), que permiten estudiar la deformación lenta y mejorar la relación señal-ruido mediante la generación de series de tiempo. La actividad del Popocatépetl experimentó un aumento a principios de 2022, marcado por la ocurrencia de sismicidad de baja frecuencia y eventos volcano-tectónicos. Seguido de explosiones y emisiones regulares de gas y vapor en los meses subsiguientes. Estos eventos persistieron hasta una transición significativa a finales de 2022 con aumento en la cantidad de explosiones y la posterior formación-destrucción de pequeños domos de lava en el interior del cráter entre mayo y junio de 2023, tras otro incremento en la actividad hacia finales de agosto y septiembre. Para llevar a cabo el análisis de los desplazamientos superficiales del Popocatépetl entre 2022 y 2023, se emplearon imágenes SAR adquiridas por el Sentinel-1A en su órbita ascendente (T005) y descendente (T143) y ALOS-2 en su órbita descendente (T153). Los resultados preliminares señalan variaciones en la velocidad promedio de desplazamiento, que podrían estar relacionadas con procesos asociados al emplazamiento de domos. Adicionalmente, estos resultados se complementan con la sismicidad, las variaciones térmicas y las emisiones de SO2 registradas en dicho periodo.

ID: 511

Eruption Dynamics during the 2016-2022 Nevados de Chillán, Chile Eruption Constrained by Surface Deformation and Effusive Flux Datasets

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A top priority of the volcanological community is to improve forecasting of the timing, location, size, and impact of eruptive hazards. The future of eruption forecasting is in models and techniques that consider the evolution of an eruption. Datasets of effusive flux and ground deformation during an eruption have great potential to clarify eruptive models with time-dependent, predictive capabilities. These datasets have been successfully used in modeling eruption dynamics at Mount St. Helens, USA (Anderson et al., 2011) and Puyehue-Cordón Caulle, Chile (Delgado et al., 2019).

We focus on the case study of the 2016-2022 Nevados de Chillán, Chile eruption. Nevados de Chillán (NdCh) is one of the most active volcanoes in Chile and is in the Southern Volcanic Zone of the Andes. It is a high-risk volcano due to its proximity to Termas de Chillán and Las Trancas, resort towns 5 and 10 km away from the crater. NdCh has been active since 640 ± 20 ka. The 2016 to 2022 eruption at NdCh is a complex eruption with many effusive and explosive events. We use topographic evolution data from the Pléiades satellites and helicopter overflights to derive extruded volume and surface deformation time series from Sentinel-1 and GNSS stations to model volume change due to magma movement. We combine these datasets to constrain models where magma, reservoir, and conduit properties constrain eruption duration and extruded volume. We evaluate these models' ability to hindcast eruption evolution.

ID: 618

Deformación del flanco occidental del Volcán Arenal, Costa Rica, detectada por InSAR entre, 2017-2023

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Una de las mejores oportunidades para identificar regiones de inestabilidad en un volcán proviene de la comprensión y el monitoreo de la deformación de su edificio, lo cual permite inferir el comportamiento de las laderas y determinar el peligro potencial.

El volcán Arenal, en Costa Rica, entró en erupción en 1968 y después de 42 años de actividad, donde se acumuló casi un medio kilómetro cubico de material en su flanco oeste, ceso su actividad eruptiva en 2010. Los últimos estudios realizados con InSAR en el volcán Arenal se realizaron en 2014, y se determinó que los flancos occidentales del volcán se mueven cuesta abajo con una tasa constante de hasta hacia el oeste de alrededor de 12 cm/año (Ebmeier et al., 2014).

Desde este último estudio, casi 10 años atrás, no hay observación de la deformación del volcán. Surge las preguntas: ¿la deformación ha acelerado? O más bien ¿se ha detenido? Para responder a estas preguntas, se implementó un estudio InSAR con imágenes SAR de Sentinel-1 entre 2017 al 2023.

Los resultados, indican que la deformación es persiste con velocidades similares a la de los últimos estudios, lo que muestra que a pesar de que la actividad eruptiva terminó en 2010, este nuevo estudio sugiere que esta deformación podría ser principalmente por compactación y estabilización del edificio volcánico.

ID: 636

The early detection of paroxysmal eruptions at Stromboli volcano through the use of pattern recognition: a tool to mitigate volcanic risk

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Early detection systems are vital components of early warning systems, primarily focusing on the scientific aspect, while civil protection authorities handle alarms and population management. Operational volcanic early detection systems play a crucial role in eruption prediction and risk mitigation, affecting both people and businesses. This study delves into short-term eruption forecasting, focusing on Stromboli, a renowned active volcano with frequent explosive activity.

Before 2019, tourists could witness Stromboli's eruptions from its crater area. However, paroxysmal eruptions in July and August 2019 led to a complete ban on tourist access due to increased risks. Recent research aims to identify precursory signs for paroxysmal events, particularly in ground deformation monitoring signals.

The study introduces an experimental system using seismic and dilatometric data to detect deformation patterns preceding paroxysmal eruptions. Pattern matching techniques are applied, evaluated through cross-validation using data from past paroxysms.

This research offers valuable insights into enhanced short-term eruption forecasting at Stromboli and similar volcanoes. Effective early detection systems, when combined with civil protection measures, can save lives, safeguard communities, and reduce disruptions near active volcanoes. The study demonstrates the use of pattern recognition in volcanic hazard assessment, paving the way for improved global integration into operational volcanic early detection systems.

ID: 652

Monitoring the deformation at Nevados de Chillan Volcano Complex, during the last eruptive cycle, using GNSS e InSAR.

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Nevados de Chillan (CVNCh) is one of the most active volcanic systems in Chile, located in the southern volcanic zone of the Andes, in the Ñuble region, near the towns Las Trancas, San Fabian de Alico, Huacho, among others. The last CVNCh eruptive cycle (2016 – 2022) was monitored in a multiparametric manner, including 5 cGNSS stations and radar interferometry tecnique (Sentinel 1A/1B), recording periods of uplift and subsidence.

Three periods of uplift are recognized from the GNSS data series: I) August 2019-July 2020, showing uplift of up to 15 cm vertically, and observable through InSAR. II) October 2020-April 2021 and III) September 2021-January 2022. GNSS data inversions using Dmodels for each inflation period suggest subtle variations in the position/orientation of the spheroid, the source geometry that shows the best fit. We highlight a)the direction of the spheroid coincides well with Cortaderas fault zone that crosses the complex, b)the volume associated with the uplift of first period is 0.02 m^3, and subsequent periods, less than 0.01 km^3, c)a clear increase in the number of seismic rupture events (VT) is observed during periods of inflation, that could indicate a magma intrusion at depth, which fueled the eruptive activity, d)the total volume extruded as domes and lava flows was estimated in about ~0.01 km^3, a third of the “geodetic volume” and e)only 8cm of subsidence were recorded during 2022. We explore the relationship between the overpressure at depth (uplift) and the effusive activity to better assessment the hazards at this active volcano.