ID: 14

Hazard and vulnerability assessment to lahars in an inactive volcano: Pico de Tancítaro, Michoacán (Mexico)

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Formation of lahars in inactive volcanoes is one of the major hazards for the people living in their surroundings, especially if the population doesn't have a recent record of this type of processes. This is the case of Pico de Tancítaro, a ~800 kyr old stratovolcano which presented its last activity ~240 kyr ago and its current geomorphological configuration led in September 2018, to the development of a lahar in the form of an hyperconcentrated flow, after an accumulated rainfall of 58 mm in 2 hour, in one of the northwestern ravines that drains the volcano and traverses the locality of Peribán de Ramos named Cutio, causing a flood that affected and originating the deeply erosion of the riverbed and walls of Cutio river. After this event, we studied the ancient lahar deposits found within the Cutio and Chondo ravines, from which we integrated a composed stratigraphic column evidencing at least 4 major lahar deposits in the form of debris flows. The features from these deposits along with a hydrological analysis of Cutio and Chondo subcatchments conducted to the numerical simulation of future lahars originated within these two ravines using the FLO-2D software, for different return periods. We also have performed a vulnerability analysis to this phenomenon using a parametric model based on the Flood Vulnerability Index. These two data sets could be used by the local authorities to integrate a hazard risk map for Peribán de Ramos, to avoid or prevent future disasters as the one of 2018.

ID: 77

Large–scale fluidisation of pyroclastic deposits by dilute pyroclastic currents

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There is increasing evidence that fine-grained deposits of pyroclastic density currents can be remobilized on a large scale, resulting in secondary concentrated flows. These flows can be a major hazard: for example, at Soufrière Hills Volcano (Montserrat) in 1997, some travelled beyond the designated danger zone to inhabited areas. Despite their hazard potential, the scale and generation mechanism of these flows are poorly understood. We demonstrate using laboratory experiments and numerical modelling that decompression following the passage of dilute pyroclastic density currents can cause rapid deposit fluidization over areas of several square kilometres and to depths of tens of centimetres. The fluidized volume can be substantially greater than that deposited by the triggering pyroclastic density current because of remobilization of previously emplaced deposits, and the fluidized volume can flow even on slopes of a few degrees. This mechanism of fluidisation should alert us to an under-appreciated secondary volcanic hazard of long–runout pyroclastic flows that can be generated by remobilisation very rapidly and with little warning.

ID: 143

Long-lasting consequences of aeolian remobilisation of ash: does the magma composition play a role?

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Aeolian remobilisation of volcanic ash represents a major secondary volcanic hazard, affecting public health and communities across spatio-temporal scales. These impacts are similar to those associated with primary ashfall but can persist longer, sometimes for decades and even millennia post-eruption. Although recurrent, aeolian remobilisation events are rarely reported, especially when compared to low-magnitude eruption deposits that often have local-scale impacts. Most published events are associated with intermediate-to-high silica magma compositions and moderate-to-large volumes of primary fallout deposits (e.g., 1912-Novarupta (USA), 1990-Hudson (Chile), 2011-Cordón Caulle (Chile)). The susceptibility of ash to remobilisation is parameterised by the threshold friction velocity U^*_{th}, which depends on surface conditions (soil moisture) and particle physical properties (size, density, morphology), properties intrinsically related with magma composition. Here, we quantify U^*_{th} for three magma compositions (i.e., basalt, andesite and rhyolite) to determine their remobilisation potential as a function of particle size. Our results show an inverse correlation between U^*_{th} and the silica content of magmas, meaning that rhyolitic particles are more easily remobilised by wind than basaltic particles. Whilst more evolved magmas clearly tend to produce larger volumes of fine material with smaller U^*_{th}, we cannot assume that basaltic magmas do not *also* produce material that is prone to wind remobilisation. In fact, local observations demonstrate that remobilisation can occur with particles of any magma composition if the threshold conditions are met. However, depletion rates of loose deposits might change through different magma compositions, and therefore, provoke a variety of consequences to the communities exposed for long-time.

ID: 179

Lahares secundarios e inundaciones en volcanes en reposo, estudio de caso: ciudad de Ibarra, volcán Imbabura-Ecuador.

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Las ciudades localizadas al pie de los volcanes pueden experimentar inundaciones y flujos de lodo (lahares) por erupciones y/o procesos erosivos. Las erupciones del Complejo Volcánico Imbabura ocurridas en el Pleistoceno Tardío – Holoceno Temprano dejaron depósitos de flujos piroclásticos y caídas de ceniza. Estos materiales fácilmente son erosionados por las lluvias estacionales y/o por terremotos. La ciudad de Ibarra se encuentra al pie del flanco norte del edificio volcánico Imbabura, y ha soportado varios eventos por inundaciones y flujos de lodo. En esta investigación documentamos 327 r[AR1] eportes de inundaciones, de los cuales al menos 110 eventos corresponden a flujos de lodo en periodo 1985-2020. Nuestro catálogo incluye información de reportes históricos, noticias de prensa, y las precipitaciones diarias de INAMHI. Las imágenes Google-Earth facilitaron identificar los abanicos de flujos recientes. Se documentó terrazas de lahares y se aplicó el método de run-up, para obtener velocidades y caudales. Los resultados indican que los lahares e inundaciones ocurren sobre los 10 mm de precipitación, sin descartar eventos menores bajo este umbral. El volumen calculado de los lahares está en el orden de ~ 1.2×10^4 m^3 a 1.2×10^6 m^3. Por otra parte, el terremoto de Ibarra M 7.0 del 16 de agosto de 1886 generó un flujo de al menos 20×10^6 m^3 causado por deslizamientos. Los lahares e inundaciones entre 1985-2019 causaron al menos 10 muertes, varios heridos y daños en la infraestructura. Trabajos futuros de modelamiento matemático pueden contribuir en el manejo del riesgo volcánico.

ID: 180

The INGV Project PROMUD: looking for a possible monitoring protocol of mud volcanoes in anthropized areas

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Paroxysmal activity of mud volcanoes, namely sudden expulsions of huge amounts of a mixture of clayey materials with associated rock fragments, salt water and gases (prevalently methane), could result in a serious threat for humans, especially if occurring in touristic sites or inside urban areas.

Mud volcano paroxysms exhibit some analogies with those from hydrothermal/magmatic systems, suggesting that similar monitoring protocol, focused on the identification of possible indicators of the transition from the background to a more energetic activity, could be implemented.

This is the main aim of PROMUD, a 3-years (2023-2025) INGV project, integrating geophysical (seismic, magnetic, geoelectric), geodetic (GNSS and tilt), bio-geochemical (characterization of emitted fluids and vegetation analysis), topographic and geomorphological data, acquired by both permanent networks and spot field surveys.

The test sites are the nature reserves of “Salse di Nirano” (northern Italy) and “Maccalube di Aragona” (Sicily, Italy) and the “Salinelle di Paternò” (Sicily, Italy). This last site, included in the heavily urbanized area of the homonymous town, is located on the western slope of Mt. Etna volcano.

An interpretative model of the spatial and time evolution of these systems will be developed from the multidisciplinary observations, in the attempt of unravelling the role played by seismic and aseismic deformation, and the hydrological cycle, in driving the transition from the background state to the paroxysm generation.

ID: 201

Towards an Operational Lahar Early Warning System at Santiaguito Volcano, Guatemala

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The Santa Maria - Santiaguito volcanic complex poses the highest threat of all Guatemalan volcanoes with significant different hazards for nearby farms and workers. Among these are lahars that occur frequently during the rainy season. Since 2019, a seismic network has been built on the flanks of Santiaguito, monitoring the barrancas that contain the lahars. We are developing a seismic-based lahar early warning system employing a short-term/long-term average detector with a station trigger associator for event confirmation, that is tolerant to station outages. The system is integrated within SeisComP, the standard platform for seismic monitoring, and, in a test phase, alerts are being sent to select end-users via Telegram.

The system detects lahars 8 to 19 minutes after their first visible seismic onsets, which provides significant warning time before flows reach the more populated lower parts of the volcano if upper flanks stations are operationnal. In this contribution, we evaluate detector performance using both a lahar catalogue and continuous records including irrelevant local seismic event for accuracy test.

Further development includes incorporating seismic amplitude and a modified earthquake early warning algorithm to enhance real-time tracking of lahars. Additionally, we work towards a machine learning-based detector for quicker event detection.

Our early warning system at Santiaguito has potential applications for other volcano observatories in Guatemala and worldwide that operate seismic networks and use SeisComP.

ID: 214

Modeling and assessing the fire hazard from volcanic activity: The case of Stromboli Island

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Volcanic-induced fires are hazardous phenomena not only because of the fire itself (as a secondary hazard), but also due to the consequences generated by the burnt soil, such as floods and landslides. The uncertainty in both the ignition location, activated by incandescent erupted materials, and the spreading behavior due to pyro-convection phenomenon in a steep volcano landscape make the fire modeling an extremely challenging task.

In the last years, several forest fire propagation models have been developed using methodologies that span from simple graphs to complex physical models or cellular automata-based models. In these models, the most used input parameters are vegetation, humidity, wind and topography to simulate the fire rate of spreading (ROS).

The integration of these models into Geographic Information Systems allows the users to classify soil, to map burnt areas and eventually to generate hazard maps.

Nonetheless, there is still a lack of a dedicated model for fires triggered by volcanic activity.

Here we present a new methodology for volcano-induced fire hazard assessment based on a new Cellular Automata Model to address computation costs, usability and limitations of accessibility of existing applications. Our model takes Sentinel-2 data as input to estimate the vegetation index and moisture content, NDVI and NDMI, respectively, evaluating the ROS on the base of fire ignition probability throughout a regular grid. The preliminary results of the methodology applied to Stromboli Island are also reported including a new volcano-induced fire hazard map and a cascading risk scenario.

ID: 348

Lahar Acoustic Remote Detection (LARD) para el monitoreo de lahares acercando; Volcán de Fuego (Guatemala) y Volcán Sangay (Ecuador)

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Johnson y colegas (2023) informaron sobre la detección remota de pequeños lahares secundarios utilizando datos de infrasonidos (senales acústicos de baja frecuencia) en el Volcán de Fuego (Guatemala). Ellos demostraron que los frecuentes eventos pequeños de lahar secundarios generan una señal infrasónica que es detectable cuando el lahar está a más de 5 km. Estas detecciones de alerta temprana en el drenaje de Ceniza preceden a la llegada del lahar real entre 20 y 30 minutos. Entonces este precursor puede ser tiempo suficiente para enviar una notificación temprana y complementar las alertas hecho por los sistemas AFM (monitoreo de geófonos), que son útiles cuando se encuentran junto a un drenaje.

Demostramos que el monitoreo por infrasonidos puede complementar el monitoreo sísmico al proporcionar un aviso de detección temprana. Describimos una metodología sencilla, simple y robusta que utiliza solo dos micrófonos infrasónicos situados en la misma ubicación con un sitio de AFM. Este método es confiable aun cuando las señales de lahar se originan en una dirección similar a una fuente de ruido de fondo infrasónico, como un volcán activo. Aplicamos esta misma metodología a señales de lahar infrasónico registradas con una serie de sensores en el volcán Sangay en Ecuador. Los resultados de Guatemala y Ecuador indican que una implementación de sistemas LARD puede ser muy útil en volcanes con actividad de lahar.

Johnson, J. B., Roca, A., Pineda, A., Mérida, R., Escobar-Wolf, R., Anderson, J. F., et al. (2023). Infrasound detection of approaching lahars. *Scientific Reports*, *13*(1), 6476. https://doi.org/10.1038/s41598-023-32109-2

ID: 427

A machine learning-based strategy to detect and catalog rain-triggered lahars through geophysical monitoring at Volcan de Fuego, Guatemala.

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Every year, dozens of lahars occur in the drainages surrounding Volcan de Fuego, Guatemala. Their behavior ranges from energetic debris flows to waned hyperconcentrated flows and are generally triggered by intense precipitation events during the local wet season. The interaction of lahars with the Earth's surface results in ground vibrations that produce a characteristic seismic record with distinctive waveform and frequency features. These observations are used for manual monitoring but may be applied to automated techniques assisted by machine learning. Herein, we trained a K-nearest neighbor binary classifier with a set of features describing the seismic record in the time and frequency domains. Each feature is sampled at overlapping 10 minute windows. We selected a subset of features that provided the best results for all four seismic stations in the experiment, two of which are permanent installations operated by the local agency INSIVUMEH, located in different lahar channels and sampling at different frequencies (50-200 sps). These features include envelope metrics, frequency content, and other derived statistical measures. The returned models hold precisions up to 95% for lahar signals with similar values for sensitivity to noise. Automated post processing of these short-window predictions yields a catalog of lahars and filters out false positive events. With this, we explore the individual and seasonal characteristics of lahars, and describe their behavior under the influence of other environmental factors (e.g., fresh PDC deposits, rainfall). We also highlight the potential of this method for automated real-time monitoring.

ID: 456

STUDY OF THE SAN NICOLÁS LAHAR DEPOSIT AT POPOCATÉPETL VOLCANO (PUEBLA, MEXICO): PRELIMINARY RESULTS.

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Lahars, highly destructive natural phenomena, pose a significant threat globally, claiming countless lives annually. Their high mobility and destructive potential contribute to their extreme danger. To better understand these events and their potential impact on densely populated areas, we investigated the San Nicolás lahar deposits located in the southeastern sector of the Popocatépetl volcano (Mexico). These extensive deposits, stretching over 57 km, reaching areas where the city of Puebla is currently experiencing rapid expansion.

Our study involves an in-depth analysis of these deposits, including thickness and volume measurements, stratigraphy refining, component analysis, and a crucial focus on quantitative textural analysis. The deposit's accessibility allowed us to study variations in clast shape-fabric, granulometry, and morphology both vertically and longitudinally. This reveals how these parameters change with flow development and particle interactions, pointing out the topography influence.

Additionally, we conducted preliminary simulations based on more accurate volume estimates, to reveal the current risk scenario for this densely populated area. Our research sheds light on the influence of topography and ravine morphology on deposit thickness, volume distribution, flow directions, and internal particle interactions. These insights, coupled with our hazard simulations, provide critical information for mitigating the dangers posed by such events in this area.

In summary, our study offers valuable and original information on the factors that determine the formation of lahar deposits and their associated hazards. By better understanding these phenomena, we can better mitigate the danger of lahars in densely populated regions.

ID: 690

Evaluation of the wall friction angle of dry volcanic materials from laboratory experiments.

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Granular materials are widely involved in several processes, from the food, cosmetic, and pharmaceutical industries, to natural phenomena such as pyroclastic density currents and landslides. Therefore, the study and understanding of their behaviour and rheology through experimental investigations is of paramount importance in terms of risk assessment, and for the development and implementation of mathematical and numerical models. Numerical simulations consider several parameters trying to reproduce the complexity of the flow but, despite the advances in the theoretical descriptions of granular flows, a gap exists between the empirical models and the experimental observations.

In this work, we present the results of the characterization of volcanic samples carried out with the FT4 Powder Rheometer (Freeman Technology). Shear tests, compressibility tests, and wall friction tests were performed to characterize the flowability of the powders. We particularly focus on the wall (or basal) friction angle, which describes the interaction of the particles with a variable-roughness substrate. Some glass beads have also been investigated, as a reference value. The results show how the wall friction angle is influenced by the ratio between the roughness of the surface and the average particle size of the samples. Moreover, the comparison with the glass beads also reveals the role played by the irregular shape of the particles.

ID: 731

Evolución de la barranca Ceniza y el impacto de su actividad lahárica en Colonia Las Palmas, Volcán de Fuego, Guatemala

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La barranca Ceniza, ubicada en el flanco sur del volcán de Fuego, es una de las barrancas con más actividad de lahares en este volcán, en especial desde el año 2021. Desde entonces, 7 erupciones han depositado material de corrientes de densidad piroclástica en la parte alta de la barranca Ceniza, el cual ha sido removido en forma de lahares durante las temporadas lluviosas, con 16 lahares en 2021, 38 en 2022 y 53 durante el 2023 hasta el 11 de octubre. Este incremento en la actividad lahárica ha provocado cambios a la barranca Ceniza y a su río homónimo, produciendo la captura de cauces de ríos vecinos y acercando los flujos de lahares a los centros poblados. A través de trabajo de campo, vuelos de dron y análisis fotogramétrico realizado por INSIVUMEH y la Universidad Estatal de Boise entre 2021 y 2023, se ha evaluado la evolución de la barranca Ceniza y del impacto que causa la actividad lahárica a algunos de los centros poblados de Siquinalá, en especial a la Colonia Las Palmas, lugar, declarado como de alto riesgo desde 2019 y que este año ha empezado a ser afectado directamente por la actividad lahárica, Considerando las condiciones actuales del terreno y los resultados de las evaluaciones realizadas, la actividad lahárica de la barranca Ceniza en las próximas temporadas lluviosas tiene la posibilidad de causar impactos severos en comunidades del área del volcán de Fuego, destruyendo infraestructura, alterando sus medios de vida y limitando sus rutas de evacuación.

ID: 752

Inclusion of volcanic sources in the procedures of the Central American Tsunami Advisory Center (CATAC)

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Recent tsunami disasters generated by volcanic sources (e.g. Krakatoa (Indonesia) - 2018; Hunga Tonga (Tonga) - January 2022) have stimulated discussions of the inclusion of volcanic sources in the procedures of the tsunami warning systems. The Central American Tsunami Advisory Center (CATAC) was established, in 2016, at INETER, Nicaragua, on request of the Central American countries. CATAC monitors the seismicity in and near the region, evaluates the possibility of and sends tsunami messages to scientific and civil protection institutions in the region to facilitate adequate actions for disaster prevention or mitigation. In the monitoring area of CATAC volcano related tsunami sources exist in the Gulf of Fonseca, a bay of the Pacific Ocean shared by Nicaragua, El Salvador and Honduras. The big volcanoes Cosiguina (1835: VEI 5) in Nicaragua and Conchagua (Pleistocene) in El Salvador form largely the coasts of the bay and the area is seismically very active. Tsunamis might be generated at both volcanoes by landslides, lahars and flank collapses even without volcanic activity triggered by heavy rains or earthquakes. Cosiguina might reactivate and cause tsunamis due to pyroclastic flows, freatomagmatic explosions or flank collapses. Tsunamis can also be generated in some lakes located in the volcanic chain in Central America, especially in the large lakes of Nicaragua. A concept is discussed to extend CATAC´s tsunami warning procedures cooperating with the seismic and volcano monitoring systems in Nicaragua, El Salvador and Honduras, expanding seismic, sea gauges and geophysical networks and integrating related software modules in CATAC´s monitoring center.

ID: 762

Application of the experience with INETER´s Earthquake Early Warning System for volcano related warnings in Nicaragua

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Starting in 2016, the seismological department of INETER developed with support of the Swiss Seismological Service (at ETH Zurich) an Earthquake Early Warning System (EEW) for Nicaragua which went public in November 2021, being still considered experimental. The system is based on INETER´s seismic network (140 seismometers; most installed in the Nicaraguan volcanic chain and along the Pacific coast); with additional sensors in the neighboring countries in Central America. Sensor data are transmitted in real time with low delay to the processing center in Managua. Alerts are sent out within a few seconds after detecting an earthquake by at least four stations using the “Virtual Seismologist” software modules (ETH) running in our SeisComP 5 system. Pre event warning time is between zero (epicenter very near) and 30 seconds (epicenter in the neighboring countries). Warning messages are sent out using several technologies: 1) Cell phone application, Early Warning Broadcasting System (EWBS) of the Nicaraguan digital TV; 4) Computer-computer communication using Raspberry Pi computers; 5) Special webpages. We propose to apply the EEW experience (extremely fast processing, low delay warnings to the population under risk) to the warnings on volcanic phenomena as lahars, landslides, volcanic bombs, pyroclastic flows, which can affect people within seconds or tens of seconds. We present examples of volcanoes in Nicaragua where the EEW experience should be applied: Lahars at San Cristobal and Concepción; volcanic bombs and volcanic ash at Telica, tsunamis at Mombacho, Concepción and in Fonseca Bay; Pyroclastic flows at Momotombo.

ID: 499

SAR polarimetric measurements to detect lava flows under different volcanic environments

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In this study, we present the application of SAR polarimetric data to observe and detect lava flows. In particular, we show how Dual Polarimetric (DP) Synthetic Aperture Radar (SAR) measurements can provide extra-value information with respect single polarization (SP) one. Satellite Sentinel-1 images are used by using a polarimetric change detector that, instead of looking at the variation of the backscatter intensity between a pair of images collected before and after the event, exploit the changes in the polarimetric scattering behaviour of the observed surface. The work aims at demonstrating that the scattering changes detected by the polarimetric signal well-correlate with the footprint of the lava flow provided by external sources. We compare the performance of the polarimetric change detector with conventional single polarization change features showing that DP always performs better than the incoherent SP measurements. To further demonstrate the additional information given by the polarimetric change detectors, we have analysed two test cases that refer to volcanic eruptions occurred in two completely different environments. The first one is related to the Etna volcano, where the lava flow happened over a vegetation-free environment; the second one is related to the Nyiragongo volcano that refers to a lava flow that covered the dense vegetated area along the volcano flank. The experimental results show that the polarimetric change detectors easly adapt to the changing environment outperforming the single-polarization detectors.

ID: 109

Landslides as a secondary hazard during volcanic crises: multidisciplinary evaluation of slope instability during the 2021 Vulcano Island (Italy) unrest

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Vulcano Island, the southernmost of the Aeolian archipelago (Italy), during the 1988 volcanic unrest was affected by a tsunamigenic landslide, which ran along the north-eastern flank of the active cone la Fossa. For this reason, the volcanic unrest started in the late summer 2021 has prompted a research activity aimed to identify the potential unstable areas which can originate landslides, capable of posing a hazard to Vulcano Porto village. A particular focus on those with tsunamigenic potential was posed. We adopted a multidisciplinary approach, based on InSAR data, high-resolution topography, geological mapping and new field-survey, identifying 13 potential source areas for landslides. These areas involve most of the La Fossa cone, except for its south-western portion; five resulted to be proximal to the Vulcano Porto settlement and at least six, located in the north-western sector, resulted to have a tsunamigenic potential through modelling tests.

The hazard associated with the landslides was assessed using two models: a multilayer non-hydrostatic code for the landslides generating tsunamis, and a depth-averaged code for granular flow for the non-tsunamigenic landslides. For the tsunamis the simulations produced the waveforms in prescribed locations and maps of arrival time, maximum water height, maximum dynamic pressure, and inundation. For the inland-only landslides, the granular flow model produced maps of maximum landslide thickness and dynamic pressure.

These preliminary results, obtained following fast evaluation criteria, under the urgency of giving prompt information as a support for decision makers during a volcanic emergency, are currently under review within the INGV project "WUNderVUL".

ID: 111

Correlation of stage height and seismo-acoustic energetics for monitoring rain-triggered lahars at Volcán de Fuego, Guatemala

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Secondary lahars, both at Volcán de Fuego and across other volcanic landscapes, produce large-volume surges at high velocities, making them erosive, destructive, and with the potential to inundate low lying areas with several layers of sediment. From May-October during the 2021 rainy season, an array of broadband seismic stations, infrasound sensors, and time-lapse cameras were deployed and monitored by BSU, MTU and INSIVUMEH along the Las Lajas drainage to catalog multiple lahar events. Time-lapse imagery of lahar flows is compared with filtered seismo-acoustic signal characteristics to ascertain stage height predictions and relationship to stage height fluxes. Using random forest regression models, we establish moderate correlations (correlation coefficient modes 0.48-0.53) with statistical significance (p-value = 0.01-0.02) between energetics in the flows and respective stage height. Energetic thresholds (weaker correlations) exist with infrasound when detecting small lahars due to storm noise, in which case, seismic and time-lapse correlations become the best model to determine corresponding stage height fluxes. We also notice that weaker correlations for both seismic and infrasound exist with sensors co-located with time-lapse cameras, as opposed to those sensors located ~1 km upstream from camera locations, likely due to preferential detection of flows adjacent to sensors and inability to correlate changes in stage height to correct energetic fluctuations. The primary goal of this research is the development of new geophysical monitoring methods that will be capable of remote and real-time estimation of evolving flow parameters in drainages around Fuego.

ID: 178

THE WILDFIRE IMPACT DETECTED BY REMOTE SENSING DATA: THE CASE OF 3rd JULY 2019 PAROXYSM AT STROMBOLI ISLAND

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Stromboli island is an active volcano in the Aeolian archipelago (Sicily, Italy) characterized by continuous mild explosive activity, interrupted by effusive eruptions, major explosions and paroxysms. These last ones release more energy respect to other eruptive activities and represent one of the most hazards in the island. In fact, during the paroxysms, the fall out of incandescent products is particularly abundant and affects not only the crater summit area but it can reach inhabited centers (Ginostra and Stromboli) involving the tourists pathways. The erupted products can impact on people and cause serious damage to buildings and infrastructures, triggering in some cases fires able to destroy the endemic vegetation and cultures. This happened during the 3rd July 2019 paroxysm, especially in the western part of the island where the Ginostra village is located. In order to map and quantify the burned areas, two spectral indexes (NDVI and NBR) were calculated by using satellite images acquired from Landsat-8, Sentinel-2 and Pleiades-1. To validate the results, the burnt vegetation areas were compared with the burnt areas extracted by the drone imagery, acquired within a few days after the paroxysm. This allowed to identify the most accurate spectral index and the most suitable satellite data for mapping the wildfires in Stromboli island. Thanks to this work, it is highlighted that wildfires represent an important secondary hazard generated by paroxysmal events at Stromboli volcano.

ID: 243

Secondary hazards and the multi-disciplinary challenge: a roadmap towards multi-hazard collaboration with the world of hydrometeorology.

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Virtually every secondary volcanic hazard is influenced by hydrometeorological factors. Lahars, mudflows, floods and landslides can be rainfall-affected. Fires spread in wind and dry conditions. Tsunamis interact with other sources of coastal inundation. Ash and gas are blown on the wind. It is neither efficient nor desirable to manage these hazards without close cooperation with hydrometeorological services, seamlessly working with emergency management and across borders as needed.

In early 2023, a workshop was held following IAVCEI in Rotorua, New Zealand, to discuss a future vision and roadmap for multi-hazard early warning systems. The workshop was attended by a mixture of operationally focused volcanologists and meteorologists, with the recently announced UN 'Early Warnings for All' initiative and progress towards advancing the Sendai Framework for Disaster Risk Reduction being the major foci. Here we present the key conclusions of that workshop, both in terms of a future 'vision' for multi-hazard operations, and a roadmap for achieving that vision. We believe that these outputs will be useful in terms of both outlining the big picture outcomes for us to be striving towards together, and a number of strategic and practical actions that will help it to happen.

ID: 423

EXPLORING GRANULAR FLOW DYNAMICS IN NARROW CHANNELS: ADVANCEMENTS IN ELECTRONIC INSTRUMENTATION AND SIMULATION FOR SCALED EXPERIMENTS

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The granular flows in narrow channels determine an increase in sound activity and seismicity, due to major interactions with the walls and the bottom of the ravine. This increase is also linked to the channel's width, probably due to a higher granular temperature, energy, velocity, and pressure of the particles, which implies phenomena such as erosion, velocity, and blockage.

Understanding these phenomena is crucial for regions susceptible to granular flows, especially in natural terrains like volcanic ravines. To explore deeper into the impact of various morphometric aspects of ravines (e.g., width and slope) and the granulometry of the granular flow, we propose an innovative experimental setup. This setup comprises a flume with adjustable width, equipped with an array of sensors such as those for measuring normal pressure, time-of-flight depth, geophones, microphones, and high-speed cameras, all supported by electronic data acquisition equipment.

The primary aim of these experiments is to collect comprehensive data on granular flow behavior within flumes with different widths. This entails measuring surface pressure on the channel walls and analyzing how energy and velocity evolve under different conditions, including variations in particle size, material volume, and channel slope. Additionally, we seek detailed insights into the audio and seismic signals generated by these flows. Our ultimate goal is to establish meaningful correlations between these signals and granular flow dynamics.

This innovative study has the potential to enhance our understanding of granular flow processes in ravines and contribute significantly to risk management in volcanic and mountainous areas.

ID: 453

Lahars scenarios in Pico de Orizaba and their relationship with climate change

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Several authors have shown that factors related to climate change can modify and accelerate volcanic eruptions. These alterations may increase the occurrence of secondary events, such as progressive melting of glaciers and increased precipitation. According to the projected models, an increase in extreme precipitation is expected under the Representative Concentration Pathways (RCP) is expected for the northern hemisphere, over the next 100 years. This study explores the impact of climatic change on the lahar phenomenon for the Pico de Orizaba volcano. This volcano is one of the active volcanoes located on the border of the states of Veracruz and Puebla, and near the cities of Córdoba and Orizaba, which together have ca. 320,000 inhabitants. Recently, lahars have been reported as result of glacier melting (1994 and 1995) and extraordinary rains (2003 and 2012). To evaluate the effects these climate changes, we generate lahars simulations using *Laharz_py* and *FLO-2D* plugin within GIS platforms. For this purpose, scenarios of lahars triggered by the extraordinary rains that occurred in 2012 were used. These parameters were used to calibrate the models. These data were modified, according to the changes in sea level and maximum extraordinary rainfall estimated for 24 h, from the RCPs for short- and long-range period. The results show a large extent of areas inundated by lahar. Within the preliminary interpretation, the decrease in potential energy seems to impact on the range of the simulations.

ID: 457

A Molecular Dynamics algorithm to study dry granular geological flows composed of non-spherical particles

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In this work we present a numerical Molecular Dynamics (MD) algorithm, optimized to be run on a parallelized Graphic Process Unit (GPU), of a 3D dry granular system composed by non-spherical particles. We show that this algorithm is able to simulate dry-granular geological flows, such as Pyroclastic Density Currents and rock avalanches, with up to 10^7 particles. The algorithm considers 6 degrees of freedom for the grains as well as a detailed description of the granular interparticle forces (inelastic collisions and static and dynamic friction forces). Additionally, we consider a simplified model for the interaction between particles and intersticial fluid (air) to explore air-driven behavior, such as size segregation, commonly observed in gravity-driven granular flows. We show that a great amount of information about the kinematic and dynamic properties of the flow can be extracted from the simulations in a grain-scale detail that could not be obtained from the commonly utilized continuum models. Our numerical method could also be enhance in order to include more complex hydrodynamic interactions, in order to study water saturated flows, such as lahars and debris flows.

ID: 529

Active OP-FTIR measurements reveals water vapor and methane chloride emissions from Salinelle mud volcanoes, Paternò (Sicily, Italy)

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About 20 km Mt. Etna south of central craters, at the contact between the volcanic and sedimentary formations, , three mud volcanoes (the “Salinelle”) discharge large quantities of CO_2 and CH4rich gases and small amounts of Na–Cl cold hypersaline waters and mud, escaping from sometimes ephemeral pools. The main site (the Salinelle “Stadium”), is located at the NW boundary of the city of Paternò: in this area, mud volcanoes activity and human factors influence each other: morphology and fluid activity is disturbed and destroyed by anthropogenic factors, but - sometimes - vice-versa. The main component of the gas phase is CO_2, followed by CH_4 and minor species. These emissions have been interpreted as the result of a mixing between hydrothermal fluids and the magmatic gases of nearby Mt. Etna.

The temporal variations in the gas fluxes and water and mud temperature, are strictly correlated to the changes in pressure of the gas/water at depth: sometimes, gas/water flow rates and temperatures have suddenly increased determining fountaining of muddy water.

While in the literature, there is a lot of compositional data on the gases, relative amounts of water vapor have never been measured before. Here, we report the first OP-FTIR measurements of water vapor and halogenated organic compound (CH_3Cl) in the Salinelle gas emission. The origin of the latter can be ascribed to oxidation processes of organic matter in the presence of halide ions, both conditions which occur in the Salinelle environment.

ID: 610

SedCas_Volcano: a novel approach to modelling decadal evolution of lahar hazard following explosive eruptions.

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Lahars are a common and potentially long-lived hazard in river basins affected by explosive volcanic eruptions. They result from the hydrological disturbance of surrounding landscapes, driven by the destruction of vegetation and deposition of pyroclastic material. These modifications typically result in heightened rainfall runoff responses, via reduced interception and infiltration, leading to increased water and sediment flux, manifesting as t lahars. With time, landscapes recover via removal of sediment, establishment and stabilisation of channels, and the redevelopment of vegetation. This recovery subsequently reduces the runoff response to rainfall and in turn limits the potential magnitude and frequency of lahars. Numerical modelling is an important approach for assessing the hazard posed by lahars. Most modelling approaches related to lahars consider the remobilisation susceptibility of pyroclastic deposits under particular conditions, or the runout/inundation potential of individual or probabilistic ensembles of flows. To date, very limited research has sought to address the longer-term (years to decade) evolution of lahar activity in affected catchments as they respond to and recover from disturbance. Here we present and discuss SedCas_Volcano, a simple model designed to simulate the longer-term evolution of lahar incidence in a catchment on the island of Montserrat that has been repeatedly disturbed by volcanic activity. Using this simple and computationally inexpensive numerical framework, we account for variability in sediment supply, vegetation cover, and rainfall. Here we will discuss the merits of this model and identify possible next steps for continued model development.

ID: 653

Change detection and monitoring of barrancas through regular UAV surveys on Fuego Volcano, Guatemala

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Secondary lahars are some of the most far-reaching and long-lasting volcanic hazards that present in active as well as extinct volcanic systems. Their erosive power can rework a channel to devastating effect and impact vital infrastructure. The effects of lahars, including erosion and deposition, can be observed with Structure from Motion (SfM) repeat surveys. DEMs can be differenced in open-source software, like CloudCompare, to estimate the volume change during lahar events. These volumes are important for monitoring erosion rates and tracking dynamic stream morphology that can threaten infrastructure, agriculture adjacent to these channels, and communities situated in previously abandoned channels. We demonstrate how low-cost, quadcopter UAVs are important tools for timely, inexpensive, and repeatable SFM land surveys in active lahar channels. Sequential surveys can be used to establish trends and anticipate the volume transport. In the summer of 2023, we flew multiple surveys of the Ceniza Barranca active lahar path at Fuego Volcano. We developed a straightforward workflow using Agisoft Metashape Pro and CloudCompare to produce difference maps demonstrating the changes in barranca morphology. We show how this end-to-end workflow streamlines the ability to present important data to the stakeholders who need to allocate land resources taking into account hazard mitigation decisions.