ID: 20

Dynamic Transport of Pyroclastic Density Currents across Topographic Obstacles

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Pyroclastic Density Currents (PDCs) are dangerous multiphase volcanic flows able to cross topographic obstacles, causing strong uncertainties in volcanic hazard models. To bridge this gap, we simulated the propagation of PDCs over hill-shaped obstacles in dynamically and kinematically scaled large-scale experiments. We varied the size of obstacles relative to the boundary layer thickness of the PDCs, while keeping their shape and the experimental input conditions unchanged, and measured the variations in flow velocity, density, temperature and deposition across the hill.
We observe four phases of PDC-obstacle interactions: (1) compression and acceleration on the stoss side, with flow detachment, expansion and deceleration on the lee side and generation of a turbulent wake immediately behind the obstacle; (2) development of an alternating thickening and collapsing jet structure separating and shielding the wake from the flow above; (3) increasing flow density destabilizing the boundary layer separation; (4) flow deceleration and wake disappearance.
Downstream of the obstacles, the dilute parts of the PDCs have lost between c. 25 and c. 50% or their initial momentum with increasing obstacle size, suggesting that dilute PDCs cannot cross obstacles that are c. 5.5 times higher than the thickness of their boundary layer. Our experiments also show that PDCs detaching from obstacles do not follow ballistic trajectories. We show that the wake dimensions are linked to the drag force exerted by the obstacle onto the flow and to a lift force inside the wake, allowing the wake to stay stable for longer distances than calculated with ballistic trajectories.

ID: 293

Thermal impact of detached ash cloud surges in 79CE at Herculaneum: a lesson for PDC hazard at Vesuvius (Italy)

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Diluted pyroclastic density currents are capable to cause huge devastation and mortality around volcanoes, and temperature is a crucial parameter in assessing their lethal power. Reflectance analysis on carbonized wood from ancient Herculaneum allowed a new reconstruction of the thermal events that impacted buildings and humans during the 79CE Vesuvius eruption. Here we show that the first pyroclastic density current to enter the town was a short-lived, very hot ash cloud surge, with temperatures of 555-495°C, capable of causing instant death of people, while leaving only a few decimeters of ash on ground, and which we interpret as detached from high concentration currents. The subsequent pyroclastic currents that progressively buried the town were mostly higher concentration PDC at lower temperatures, between 465-390 and 350-315 °C. Charcoal proved to be the only proxy capable of recording multiple, ephemeral extreme thermal events, allowing us to reveal for the first time the real thermal impact of the 79CE eruption. The lethal impact documented for diluted PDC produced during ancient and recent volcanic eruptions suggests that such hazard deserves much more consideration at Vesuvius and elsewhere, especially the underestimated hazard associated with hot detached ash cloud surges, which, though short lived, may expose edifices to severe heat damages and people to death. Fitting red zones to shelter people from this kind of hazard in case preventive full evacuation is not achieved is essential to protect lives.

ID: 366

Dynamic topography and pyroclastic density current (PDC) hazard at Volcán De Fuego, Guatemala, revealed using a multi-source digital elevation model (DEM) timeseries.

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The devastating June 3rd 2018 eruption of Volcán De Fuego, Guatemala, produced major PDCs down the Las Lajas (East), Ceniza (South) and Seca (West) barrancas. Compared to previous PDCs down the barranca, the PDCs in the barranca Seca took a new, unusually sinuous path. This affected its runout and therefore hazard relative to the previous, more direct path followed by previous PDCs.

To assess why this path change happened, we combine activity reports in the months and years before June 2018, a multi-source high-resolution DEM timeseries from UAVs and TanDEM-X, PlanetScope Optical imagery and PDC modelling using the two fluids version of VolcFlow. From these, we investigate the cumulative roles of both erosional and depositional processes in causing the observed topographical changes which altered the preferential PDC path. We also characterise the volume of the 2018 PDC deposits in barranca Seca using a mass-balance approach.

We identify key events in the years before June 2018, relatively minor in isolation, that contribute towards this change. The infilling of the barranca Seca by a c. 5 million m^3 PDC in May 2017, and following downcutting during La Niña rainfall in late 2017, contributed to the opening of a less active channel that eventually became the primary path for the June 2018 PDCs. Our mass-balance results also support the emergent hypothesis of PDC triggering via the collapse of 'perched tephra stores' at Fuego. Our PDC modelling further evidences this change of path associated with the observed topographic change.

ID: 458

Fluid Entrainment, Particle Concentration and Flow Mobility in Pyroclastic Density Currents

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Explosively erupting volcanoes generate complex, high-velocity mixtures of gas and particles that can be dominated by turbulence and shocks in dilute domains and by granular interactions in more concentrated regions of flow. The engulfment (entrainment) and mixing of ambient gas can play a predominant role in the dynamics of these flows from determining the height of erupting columns to the propagation of pyroclastic density currents. In this work we conduct a series of highly resolved multiphase numerical calculations to trace parcels of air that are mixed in turbulent structures and examine the two-way feedback in dynamics, and conduct complementary simulations using discrete element simulations to understand particle-fluid and particle-particle interactions in the concentrated parts of the flow. These calculations are presented in the context of a series of validation studies completed over the past several years, and are applicable to both gas and water saturated flows. Importantly, we present integrated particle and gas flux calculations that can be readily incorporated into recent multilayer depth averaged approaches to improve predicted runouts. Many previous parameterizations of entrainment are based on experiments of relatively dilute flows, usually with water as the working fluid. We show that values from previous parameterized entrainment coefficients can vary significantly from predicted entrainment in particle-stratified currents and present a unified framework for evaluating entrainment and the resulting impact on the thermal structure of the currents.

ID: 549

Examining Pyroclastic Density Current Rheology and Retrogressive Collapse through Granular Flow Experiments

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Long runout pyroclastic density currents (PDCs), propagating over 5km, are typically generated from eruption column or dome collapses. Instead, during the June 3rd, 2018, Volcán de Fuego (Guatemala) eruption, incremental collapse of perched tephra and lava flow deposits generated PDCs with ~50 million m^3 volume. These PDCs reached over 12km on the southeast flank, devastating the San Miguel Los Lotes community. Since 2018, Fuego has produced several other PDCs associated with the collapse of perched deposits. Such metastable deposits accumulate on 25^o to 40^o slopes over months to years, and collapse during heightened activity with frequent small-volume PDCs. The phenomenon remains poorly understood due to lack of direct observation or identification in geophysical data.

Monitoring difficulties make analogue experiments a vital tool. Here, we utilise a newly developed geophysical flow flume (University of Edinburgh) to first, examine the rheology of sand avalanches as PDC analogues. Through high-speed imaging and particle image velocimetry (PIV), we measure granular temperature, crucial for understanding rheology and flow-substrate interactions. Findings suggest agitation concentration at flow base magnified at higher velocities. Subsequently, we investigate how granular flows destabilise erodible substrates, weakened through granular heating. When shear stresses reach sufficient levels, flows initiate the collapse of a critical volume of the underlying deposit, subsequently triggering a retrogressive dilation wave which induces complete failure of the pile. This study explores PDC dynamics and a unique process at Fuego: PDCs triggered by the collapse of perched material. Understanding this phenomenon will aid refining PDC prediction, hazard assessments and mitigation.

ID: 21

Runout and Hazard Characteristics of Pyroclastic Density Currents Overcoming Topographic Obstacles

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Pyroclastic Density Currents (PDCs) have the ability to propagate across significant topographic obstacles, potentially impacting areas that may not have been previously considered in hazard planning. We performed large-scale experiments of PDCs interacting with hill-shaped obstacles of varying size and measured the spatiotemporal variations in flow velocity, density, temperature and deposition up to 30 m runout to understand the effects of the obstacle on the flow and its associated hazards.
Immediately downstream of the obstacles, we see the formation of a turbulent wake which dimensions increase with obstacle size. After the hill, the flows have lost up to c. 74 % or their initial momentum due to partial blocking of the dense underflow. The dilute turbulent overriding surge of the PDCs have also lost up to c. 50 % of their initial momentum with increasing size of the obstacles.
However, flow velocity, density, suspended particle load, final runout distance and deposit characteristics are remarkably similar for all obstacle scenarios. Flow temperatures are also hotter for longer distances downstream of larger obstacles. This implies that topography and blocking have little consequences on downstream hazard impacts and that processes countering the immediate momentum loss are present. We show that obstacles create a significant drop in flow density but also allow the flows to maintain their new density contrast for longer as particles are better suspended. On another hand, internal gravity waves propagate unhindered and reach the slowing flow head more efficiently, allowing similar runouts.

ID: 52

Stepping into the Flow: Deciphering the Influence of Topographic Steps on the Dynamics and Hazards of Pyroclastic Density Currents

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Pyroclastic Density Currents (PDCs) are high-energy, hot multiphase flows that pose significant risks in volcanic regions. PDCs frequently traverse complex topography, such as topographic steps that can be over 100m high, which typically formed by the emplacement of lava flows and subsequent erosion. Kelfoun and Gueugneau (2022) explored the role of steps in generating pore pressure in the basal layer of dome-fed PDCs; however, their focus was primarily on steep slopes exceeding 30 degrees. Our study is inspired by the observation of a 20-m step located in the Las Lajas valley on a shallow slope (~5 degrees), roughly 12 km from the source at Volcán de Fuego, Guatemala. On June 3 2018, the Fuego PDCs reached this step and moved up to c.3km downslope, demonstrating extreme mobility. In our study, we use 3D multiphase flow simulations to examine how varying combinations of flow thickness, step height, and slope in the basal avalanche of PDCs can impact the regeneration of excess pore pressure. The interaction between PDCs and topographical steps can induce substantial modifications in flow behavior by altering the solid concentration of the basal avalanche and affecting its overall rheological properties. Additionally, we discuss the impact of topographic steps on the fragmentation-induced fluidization (FIF) and ash elutriation mechanisms. The findings are particularly pertinent for evaluating the potential risks associated with PDCs in regions characterized by varied topographies and provide a foundational framework for future studies exploring the interaction between PDCs and landscape features.

ID: 86

PYROCLASTIC DENSITY CURRENT HAZARD MAP OF MISTI VOLCANO, AREQUIPA, PERU

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The eruptive record of Misti volcano includes numerous episodes of explosive activity associated with the emplacement of pyroclastic density currents (PDCs). The associated PDC deposits are mostly confined to the Chili River canyon and the ravines located on the SW, S and SE flanks of the volcano; such as San Lázaro, Huarangal and Agua Salada, Arequipa.

To build the new hazard map of PDCs at Misti, several steps were undertaken: 1) collecting key parameters from past PDCs and their deposits at both Misti and analogous volcanoes including volumes, runout distances and inundation areas, 2) defining eruptive scenarios, 3) calibrating and randomly sampling the model input parameters using various probability distributions, 4) processing of the digital elevation model (DEM), 5) defining and randomly sampling the range of source conditions, and 6) running an ensemble of numerical simulations using the one-phase and two-phase versions of the VolcFlow code on a computer cluster.

Results show the probability distributions of both the dense and dilute parts of the PDCs around Misti volcano. The proposed hazard scenarios are based on three ranges of flow volumes (1 to 50 million m^3, 50 to 100 million m^3 and 100 to 1000 million m^3); corresponding to hazard scenarios and VEI (Volcanic Explosivity Index) 2 and 3 (high danger), VEI 3 and 4 (moderate danger) and VEI 5 (low danger), respectively. The resulting probabilistic map and its associated notice is a tool that will be used for territorial planning and adequate volcanic risk management in the city of Arequipa.

ID: 225

Understanding and simulating genesis of dilute PDCs and their decoupling

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Pyroclastic currents are very destructive and their complex behavior makes the related hazards difficult to predict. The code VolcFlow has been developed to simulate the emplacement of both the concentrated and the dilute parts of pyroclastic currents using two coupled depth-averaged approaches. Interaction laws allow the concentrated current (pyroclastic flow) to generate a dilute current (pyroclastic surge) and, inversely, the dilute current to form a concentrated current or a deposit. The model reproduces the relationships observed in the field: the increase in surge production in constricted valleys, the decoupling between the concentrated and the dilute currents, and the formation of surge-derived concentrated flows. We compare the results of the model with the field data for the eruptions of Montserrat in 1997 and Merapi in 2010, and demonstrates that the approach is able to reproduce the natural emplacements with good accuracy.

However, some physical laws are empirical and mechanisms causing the separation into the concentrated and dilute layers, as well as the mechanism causing their high mobility are still unclear. We also present a conceptual model based on field observations, laboratory experiments, and numerical modeling that unifies these mechanisms. Our model shows that dilute PDCs are caused by the fall of fine volcanic particles onto steep, irregular topography. The ambient air entrapped during the fall both induces high fluidity in the pyroclastic flow by increasing the air pressure in its pores and creates the pyroclastic surge through expulsion of the finest particles.

ID: 315

A first preliminary attempt to experimentally calculate the coefficient of restitution of highly irregular volcanic particles

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Geophysical granular flows are gravity-driven conglomeration of discrete macroscopic particles that can move in response to gravity. In particular, dry volcanic granular flows are typically polydisperse in terms of grain size and density and their flow characteristics are mainly governed by particle-particle collisions and frictional forces acting at the boundaries. The parameter measuring the energy dissipation during the particle-particle collisions is the restitution coefficient (e), which is proportional to the original energy fraction, stored in the particles, that is restored to them after the collision. e is fundamental in computational fluid dynamics (CFD) numerical models to simulate multiphase granular flows because it appears in several relationships required to solve the particles motion and the particle-particle momentum exchange. e calculation for highly irregular volcanic particles is very challenging and remain an unsolved problem. We tried to address it first by making particles collide by means of a pendulum-type instrumental apparatus. e was calculated for particles with different density (ρ) and diameter (d) and the experimental data were used to obtain linear relationships between e and the investigated parameters. A multiple regression was applied to all data to predict the value of e knowing the values of d and ρ. The obtained law was finally validated against some large-scale experiments on volcanic dry granular flows by means of the MFIX CFD tool, obtaining a better agreement between simulated and experimental flow velocities. Improving our knowledge on e is fundamental in hazard assessment and planning strategies to minimize the impact of these phenomena.

ID: 403

Numerical modeling of the June 3rd, 2018, pyroclastic density currents at Fuego volcano (Guatemala): implications for flow decoupling hazards

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Most casualties caused by recent pyroclastic density currents (PDCs) are due to the unpredicted decoupling of the dense and dilute transport regimes, where flows rapidly inundate valley banks and can consequently travel kilometers away from their detachment/overspill locations as ash-cloud surges and/or overbank flows. The causes and physics behind the decoupling processes of PDCs remain poorly known despite its high dangerousness.

In this work, we present results of numerical simulations performed with the two-phase version of the VolcFlow code (Kelfoun, 2017), aimed at reproducing the sequence of PDC events on June 3rd, 2018, at Fuego volcano (Guatemala) that led to several hundred casualties on the southeast flank. Using field data collected shortly after the eruption and high-resolution Digital Elevation Models, we test the ability of the code to simulate 1) the progressive infilling of the barranca Las Lajas by the two first PDC events, and 2) the overspilling of the third PDC unit and associated overbank flows towards San Miguel Los Lotes. Successive changes in the source conditions, geometry of the channel (i.e., channel capacity) and local PDC internal properties (velocity, thickness, and mass flux) inside the channel at the decoupling/overspill site were first estimated. Then, volume-, mass-flux-, and distance-dependent critical channel capacities for similar flow decoupling processes are being developed from each potentially affected barranca surrounding Fuego to better estimate areas prone to such unconfined PDCs. Results of this study will be disseminated for broader community-based PDC model validation, benchmarking, and forecasting efforts.

ID: 763

Granulometric and component analysis of deposits associated with the ~760-year eruption of Tacaná Volcano, Mexico.

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The Tacaná volcano is an active stratovolcano of andesitic composition, located in the state of Chiapas, southern Mexico; and in the department of San Marcos, western Guatemala. It has an elevation of 4,060 m a.s.l. and has had eruptions from the late Pleistocene to the present, one of its most recent eruptions being determined by Macías *et al*., 2018 at ~760 ± 30 BP.

The ~760 BP eruption consists of pumice-fall deposits alternating with dilute pyroclastic density currents (PDCs) and ashfall deposits.

Granulometric and component analysis was performed on 29 samples from the summit of Tacaná Volcano, collected from 2017 to 2019. Petrographic analysis was also performed on some of the samples analyzed, to obtain more detailed information on the mineralogical characteristics.

The results obtained indicate that most of the samples present a granulometric distribution that varies from unimodal in the air falls with modes in -3ϕ to bimodal in the PDCs with modes in -3 and 2ϕ. Composed of juvenile fragments of 30%, lithic accessories 20%, pumice 12%, crystals 3% and accidental material 35% in air falls. In the vicinity of the lake to the interior of the crater, the walls are composed of a volcanic gap that covers a layer with abundant accretional lapilli, indicative of the PDCs. The above features, such as the percentages of accessory components and accretional lapilli, indicate that moisture was probably present during the eruptions. Therefore, the present eruption analyzed highlights the danger to which the population around the Tacaná volcano is subject.