Editorial: Field Data, Models and Uncertainty in Hazard Assessment of Pyroclastic Density Currents and Lahars: Global Perspectives

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Keywords

volcanology, volcanic hazard assessment, uncertainty, Pyroclastic density currents (PDCs), Lahars

Contribution to the field

Pyroclastic density currents (PDCs) and lahars are two of the most destructive phenomena that are generated at volcanoes worldwide. Therefore, assessing their volcanic hazard is a primary step towards the estimation (and reduction) of volcanic risk around volcanoes. In this Editorial, we present a compilation of Original Research manuscripts that study PDCs and lahars, and contribute to different components of their volcanic hazard assessment. Taking these global perspectives into account, we also provide our own expert judgment on what future directions might be taken to keep improving these PDC and lahar hazard assessments moving forward.

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Pyroclastic density currents (PDCs, e.g. Sparks et al., 1978; Branney and Kokelaar, 2002; Sulpizio et al., 2014; Dellino et al., 2019) and lahars (e.g. Manville et al., 2009; Vallance and Iverson, 2015; Thouret et al., 2020) are two of the most destructive volcanic phenomena. They can generate enormous losses of life (e.g. Auker et al., 2013; Brown et al., 2017; Baxter et al., 2017), as well as extensive structural damage to buildings and infrastructure within tens of kilometers from their source (e.g. Valentine, 1998; Baxter et al., 2005; Jenkins et al., 2015). Hazard assessments of PDCs and lahars represent the foundation for estimating the substantial risk that these volcanic mass flows pose to the human environment.

Unfortunately, these hazard assessments are complicated by the spatio-temporal complexity associated with the processes of triggering, propagation (including flow transitions) and emplacement of PDCs and lahars (e.g. Iverson, 1997; Pierson and Major, 2014; Dufek et al., 2015; Dufek, 2016). This natural variability (or aleatory uncertainty), alongside incomplete and imperfect knowledge (or epistemic uncertainty, cf. Woo, 1999; Connor et al., 2001; Marzocchi et al., 2004; Sparks and Aspinall, 2004; Marzocchi and Bebbington, 2012) should ideally be incorporated into the mass-flow hazard assessment (e.g. Bayarri et al., 2009, 2015; Spiller et al., 2014; Neri et al., 2015; Tierz et al., 2016, 2017, 2018; Mead et al., 2016; Mead and Magill, 2017; Bevilacqua et al., 2017, 2019; Sandri et al., 2014, 2018; Wolpert et al., 2018; Hyman et al., 2019; Rutarindwa et al., 2019). At the core of any volcanic hazard assessment resides the volcanological knowledge available for the volcano of interest and/or *analogous* ones, including information about the sources of uncertainty (e.g. Newhall and Hoblitt, 2002; Aspinall et al., 2003; Sandri et al., 2012; Pallister et al., 2019; Tierz et al., 2019; Tierz, 2020; Cioni et al., 2020).

In this Research Topic (RT), we have attempted to gather and showcase volcanological expertise from around the globe, related to any *component* of PDC and lahar hazard assessment: i.e. volcanological field data collection, analysis and interpretation; experimental and/or numerical and/or statistical modeling, including uncertainty quantification. Volcanic systems in 12 countries and 6 continents have been studied (Fig. 1a). Below, we summarize the main findings of each article, highlighting the most relevant methodological and volcanological aspects.

Zhao et al. provide a thorough description of the characteristics and spatial distribution of PDC lithofacies, including systematic changes with distance from the vent and topography of the volcanic edifice, associated with the VEI 7 Millennium eruption (946 AD) of Tianchi volcano (China-DPR Korea border). The work underlines the significant PDC hazard from past (and future) eruptions at Tianchi, and recalls the notable thermal hazard of PDCs.

Takarada and Hoshizumi re-evaluate the distributions and eruptive volumes of large-scale PDC (up to 166 km runout) and tephra fall deposits derived from the caldera-forming Aso-4 eruption (87–89 ka) of Aso volcano (Japan). The total eruptive volume of the Aso-4 eruption is about 1.5 to 3 times larger than the previous estimation, making it now a M8.1–8.4 (VEI 8) super-eruption.

Silleni et al. develop a new isopach-based method to estimate (large-magnitude) ignimbrite volumes, using extrapolations of the pre-eruption topography to better constrain epistemic uncertainty. The method should be reproducible for other topography-controlled ignimbrites and, applied to the M7 Campanian Ignimbrite eruption (~40 ka) of Campi Flegrei caldera (Italy), significantly reduces the epistemic uncertainty in total erupted volume compared to previous estimates.

Gillies et al., by means of a comprehensive field-mapping at Mt. Ruapehu volcano (New Zealand), have identified 12 new PDC deposits from at least 10 previously unknown flows. Concentrated-flow behavior and the approximate age ranges of these flows were inferred from lithofacies, stratigraphy and whole-rock geochemistry. The article highlights the capability of Mt. Ruapehu to generate different sizes and styles of PDCs, a key element for future hazard planning.

Gilbertson et al. propose an alternate mechanism for secondary hydroeruptions in PDC deposits. Analogue experiments suggest hydroeruptions are possible where low-permeability (fine-grained) beds are capped by high-permeability (coarse-grained) beds through a drag-based mechanism. Gas pockets and explosive failure may occur if gas flow supports fluidization of the fine, but not coarse particles. This expands the range of physical mechanisms for a secondary hazard often poorly represented in the geologic record.

Walsh et al. analyze lahar dynamics using a 3-component, broadband seismometer at Volcán de Colima (Mexico). The study argues the merits of utilizing all three seismic components to analyze the spectral content of ground motion parallel to and across the drainage channel. They further relate these seismic analyses to the flow rheology and physical processes of the observed lahars.

Córdova et al. combined fieldwork, laboratory, remote-sensing and numerical-modeling techniques to infer the relation between a hummocky field at Chalupas caldera (Ecuador), and the partial collapse of the post-caldera Buenavista lava dome. The work evidences the advantages of integrating *classical* and modern techniques for the interpretation of volcanological phenomena, and sheds light on the directionality, timing and approximate volume of the associated breccia flow.

Dille et al. tested the effectiveness of two flow models for simulating rain-triggered lahars at Karthala volcano, Grand Comore Island. Karthala has a lower gradient and poorly incised channels that can limit the reliability of models compared to stratovolcanoes. Field methods to improve the Digital Elevation Model (DEM) and constrain inputs improved accuracy of the results. This article demonstrates approaches that may improve hazard assessment accuracy in difficult-to-model settings.

Gueugneau et al. numerically investigate the Mount Pelée May 8th, 1902 pyroclastic current, using a two-phase model that simulates both the block-and-ash flow and the ash-cloud surge. The study discusses conflicting interpretations of the pyroclastic current dynamics, either a blast related to a laterally-oriented dome explosion or an ash-cloud surge derived from the block-and-ash flow.

Charbonnier et al. conducted a multi-disciplinary study on the PDCs generated by El Misti volcano (Peru) in its reference eruption for hazard assessment in Arequipa (>1M residents). Combining new field-mapping with a 2-m resolution DEM, they re-assessed the area invaded by PDCs and their total bulk volume. The latter is used in the VolcFlow model to assess the probability of similar PDCs impacting specific valleys, which is key to understand potential effects of PDCs on Arequipa.

Patra et al. describe a flexible methodology for characterizing models of geophysical flows and the underlying assumptions they represent, using a statistical approach over the full range of applicability of the models. They present the method by comparing three different models arising from different rheology assumptions in the case study of a block-and-ash flow propagating on the SW slope of Volcán de Colima (Mexico).

Clarke et al. present a comprehensive procedure for PVHA of PDCs; from primary field-data collection, analysis and interpretation, to the physical/statistical modeling required for uncertainty quantification. The method is applied to Aluto volcano (Ethiopia) but is transferable to other volcanic systems. A basic understanding of past eruptions remains crucial to design and justify the modeling strategy but initial PVHA of PDCs may be possible at data-scarce volcanoes, if supported by data from analogue volcanoes.

Spiller et al. introduce a probabilistic model for the cessation of PDC activity that accounts for the time elapsed from the last PDC. They combine this model with a structured and reproducible uncertainty quantification framework that allows robust, yet rapid, PVHA using observational data for dome-collapse PDCs, numerical simulations of TITAN2D and Gaussian process emulators. The method is applied to a hiatus in volcanic activity, or post-eruption unrest context, at Soufrière Hills Volcano, Montserrat.

In summary, we suggest that increased connections between the PDC/lahar scientific communities worldwide will result in further advances in the field. We believe that future hazard assessments will require enhanced multi- and inter-disciplinarity among volcano scientists; continuous communication and mutual learning between *observational* volcanology and physical/statistical modeling aimed at simulating eruptive scenarios and/or quantifying uncertainty in PVHA (Fig. 1b).

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Authors' Statement

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Figure captions

Figure 1. Summary of present and future global perspectives in the field of volcanic hazard assessment of pyroclastic density currents (PDCs) and lahars derived from this Research Topic. (a) Global distribution of countries where volcanic systems have been analyzed in the Research Topic, divided according to whether the main object of study were PDCs or lahars (NB. Two different studies, one for PDCs, **Patra et al.**, and another for lahars, **Walsh et al.**, were presented for Volcán de Colima, Mexico). Map generated using Quantum Geographical Information System (QGIS Development Team, 2021), and Eurostat GISCO Geodata for the country boundaries (1:3 Million

Scale. Downloaded 25 January 2021). (b) Interrelationships between three main approaches commonly used in volcanic hazard assessment of PDCs and lahars. One is based on collating fundamental volcanological knowledge for the volcanic system of interest (and/or analogue volcanoes). Both scenario-based as well as probabilistic volcanic hazard assessments (PVHA) build upon this primary volcanological knowledge. Currently, there is a balance between the degree of physical detail and the uncertainty accounted for that can be achieved with scenario-based and PVHA methods. We argue that the three approaches are complementary and mutually beneficial, and that they should be increasingly merged in future hazard assessments. We also stress the key importance of acknowledging the presence of epistemic uncertainty on all three approaches, and of trying to quantify it as best as possible.

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Figure 1.TIFF

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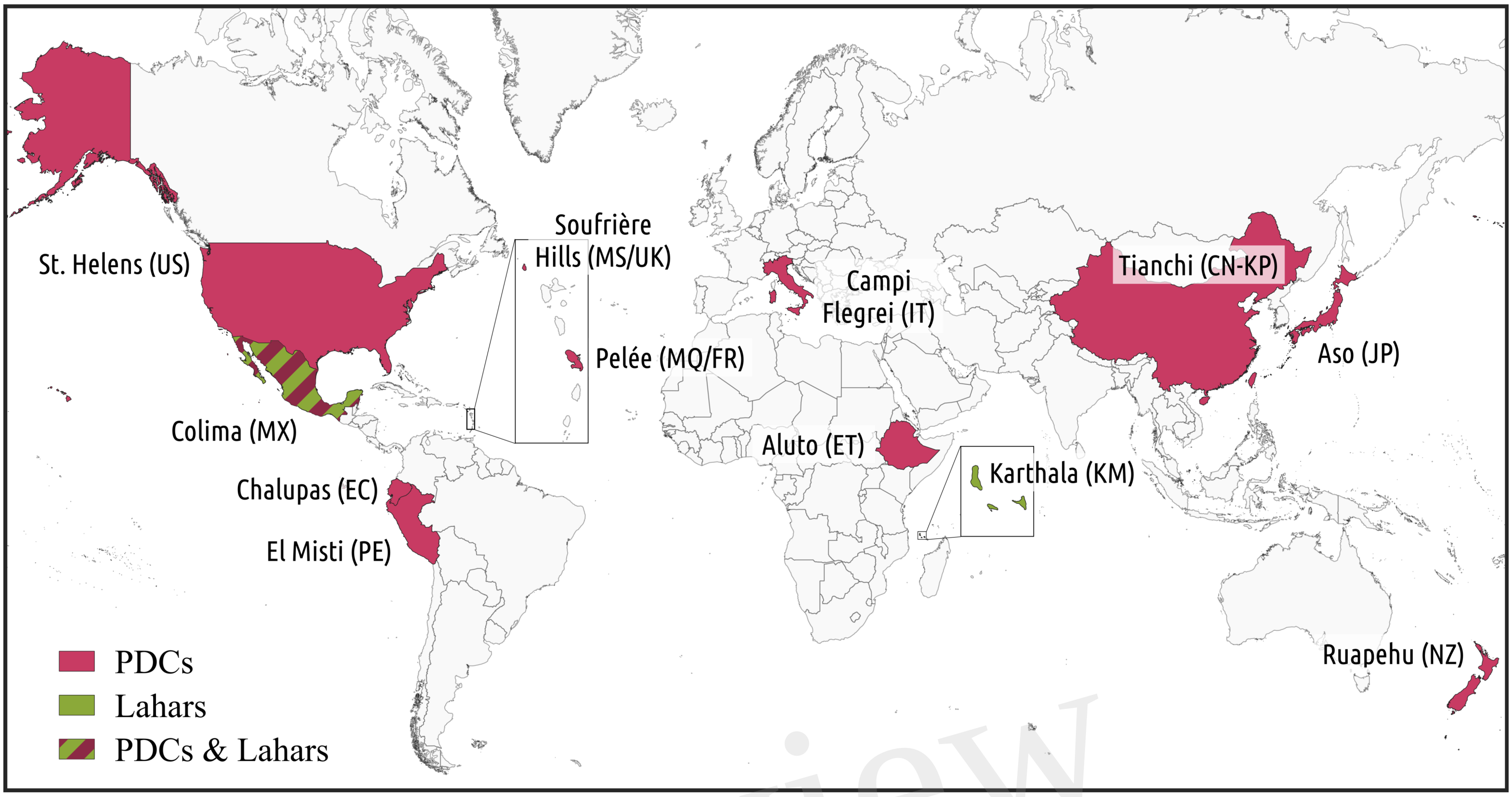

b