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Assessing lahar hazards at Cotopaxi volcano (Ecuador) controlled by volcanic eruptions and glacier retreat

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Lahars rank as one of the most destructive hazards at Cotopaxi volcano (5897 m asl) due to the presence of a massive glacier cap, the frequency of eruptions and the high population density in the surrounding, potentially inundated valleys. In 1877, Cotopaxi experienced the last major VEI 3-4 eruption, producing syneruptive lahars of 60-100 million m^3 that travelled hundreds of km downstream. Few lahar simulations based on empirical or fluid dynamic approaches exist for Cotopaxi, but here we introduce a calibrated numerical debris flow model capable of reproducing confluence and erosivity of flows.

In this study, we back-calculate the well documented 1877 lahar event using the 2D debris flow model RAMMS, which is based on the Voellmy-Salm friction approach and includes an entrainment algorithm. We first evaluate the sensitivity and range of possible model input parameters by systematically varying model inputs for release volume, density and frictional resistance (Coulomb type friction μ [-] and turbulent friction ξ [ms^{-2}]). Supported by a probabilistic analysis, we find that a choice of historical and field-derived calibration metrics of the 1877 lahar event along the northern lahar trajectory can well constrain most likely input parameters for frictional resistance. Our results show that modelling large-scale primary lahars at Cotopaxi is strongly controlled by very small values for Coulomb friction μ (0.005-0.015). Finally, we apply the calibrated model to typical eruption scenarios of Cotopaxi (VEI 1 to >4) in order to enable a realistic lahar hazard representation.

Considering the rapid rise of the equilibrium-line altitude of tropical Andean glaciers together with reports on secondary lahars at the eastern flank of Cotopaxi without any clear trigger, we hypothesize a process-based link between the two phenomena. Geoelectrical and refraction seismic field surveys near the glacier margin (5000- 5300 m asl) have been conducted in order to gain a better understanding of the structure, conditions and degree of freezing of the subsurface, which is dominated by loose pyroclastic material and interbedded lava layers. The tomography results are highlighted within the concept of permafrost degradation and accompanied material weakening as potential triggering mechanism for secondary lahars.

Here we show 1) a carefully calibrated numerical lahar model at Cotopaxi capable of reproducing previously non-respected effects such as confluence, erosion reach and propagation speed, and 2) first measurements addressing the role of glacier retreat on the formation of secondary lahars. Our results contribute to the multi-hazard risk assessment in the RIESGOS project funded by the

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