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Understanding mass-wasting processes in sub-tropical active volcanoes

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Mass-wasting processes such as landslides and debris flows (lahars) are common processes in active volcanoes. During eruptive phases, unconsolidated material is continuously added on the volcano flanks, enhancing the natural instability of slopes. The first significant rainfall after deposition of the tephra layer usually initiates sediment remobilization. However, most part of sediment yields is produced by the long-term erosion and reworking of valley-filling pyroclastic flow deposits. In addition, volcaniclastic steep slopes and saturated volcanic soils containing sensitive clays are highly susceptible to earthquake-induced landslides. Popocatépetl and Volcán de Colima are the most active volcanos in Mexico and are located in a climatic region where intense rains persist from June to October. In both volcanoes, earthquakes and rainfalls are the two main common mechanisms in triggering landslides and lahars. On 21 January 2003, a 7.6 M earthquake near Tecomán (Colima) induced small landslides on the slopes of the Volcán de Colima; no rains followed the event so the material remained at the toe of the scars. The 7.1 M Central Mexico earthquake, occurred on 19 September 2017, triggered several landslides on the slopes of the Popocatépetl volcano, removing large masses of old pyroclastic flow deposits. Approximately 10 days later, intense rainfalls remobilized the material forming high-viscous mud flows, containing abundant tree trunks (i.e. woody debris flow). Popocatépetl volcano is highly vegetated with a dense pine tree forest up to 3700 m a.s.l.; in the vegetated areas, soil slips are quite common during the rainy season. Debris and trees accumulate and clog main drainages, to be then removed forming woody debris flows as observed during intense rainfalls in 2010. Since the most persistent modern activity of Popocatépetl consists of small vulcanian eruptions accompanied by ash fall, the last observed lahars were related to slope instability, except for the 2001 event that was triggered by a pumice flow that melted part of the still existing glacier and formed the lahar. In contrast, the flanks of Volcán de Colima are constantly renewed with fresh unconsolidated material from rock falls and pyroclastic flows produced by the partial collapse of the summit domes. During the rainy season, more than 20 lahars per year are recorded. Small flow events (peak discharge < 100 m3/s) usually occur at the beginning of the rainy season, triggered by less than 10 mm of accumulated rains and enhanced by a hydrophobic effect of soils; a critical threshold rainfall was identified for this type of events. Late in the rainy season, when tropical rains associated to hurricanes land along the Pacific Coast, large lahars with maximum peak discharge of 900 m3/s can occur, lasting several hours. In these cases, lahars start after several hours from the beginning of the rainfall and the arrival of main surge waves is controlled by the hydrological characteristics of the watershed (rainfall intensity, runoff and peak discharge). The research perspective is the use of catchment hydrology, combined with distributed sensor networks, for the designing of an Early Warning System (EWS) for hurricane-induced lahars in sub-tropical regions.