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What can hydro-meteorological variables tell us about debris flow occurrence?

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In Alpine regions, debris flows are typically triggered by rainfall-related weather conditions - including short duration storms and long-lasting rainfall - or intense snowmelt, which sometimes also occur in connection with rainfall. Since rainfall is an important but, given considerable observational uncertainties together with the highly localized character of debris flows, problematic factor for debris flow forecasting at the regional scale, we investigated other hydro-meteorological variables when debris flows were triggered and developed a probabilistic debris flow susceptibility model. For this, we first setup a conceptual hydrological rainfall-runoff model for the study region Montafon, Austria, in which debris flows at 38 different days were recorded in the headwater catchments between 1953 and 2013. A probabilistic analysis of hydro-meteorological variables including precipitation, temperature, soil moisture, evapotranspiration and snow melt, as well as their temporal evolution over days prior to the debris flow events, was used to capture different trigger conditions. From these different characteristics and, importantly, ignoring precipitation itself, we identified the trigger of historical events to allow a trigger-separated extraction of catchment states. Subsequently, four Naive Bayes Classifier models were used to compute the daily debris flow susceptibility of the watershed, ranging from a simple rainfall-only model to a multi-parameter hydro-meteorological model differentiating between trigger types. The performance of the models was assessed using receiver operating characteristic statistics. Our results acknowledge the presence of different catchment regimes at debris flow occurrence. The results suggest that on 23 event days debris flows were triggered by convective rainstorm events, while on 12 days debris flows occurred due to gradual soil moisture build-up during/after long lasting rainfalls. On six days snowmelt played an important role. Measured event day precipitation (which was no criteria for trigger identification), significantly differs in dependence of the prevailing process. Further, we find that the trigger-type resolved prediction of debris flow susceptibility based on the hydro-meteorological catchment information outperformed the simple rainfall-only approaches, with higher true positive rates as well as lower false alarm rates. We conclude that for our study region, hydro-meteorological information improves the prediction of debris flow susceptibility and – in combination with weather forecasting – the susceptibility model may be developed into a probabilistic forecasting tool for debris flows.