Multi-parametric observations of debris-flow initiation at the headwaters of the Gadria catchment (eastern Italian Alps)

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The complete understanding of the mechanisms controlling debris-flow initiation is still an open challenge in landslide research. Most debris-flow models assume that motion suddenly begins when a large force imbalance is imposed by slope instabilities or the substrate saturation that causes the collapse of the channel sediment cover. In the real world, the initiation of debris flows usually results from the perturbation of the static force balance that retains sediment masses in steep channels. These perturbations are primarily generated by the increasing runoff and by the progressive erosion of the deposits. Therefore, great part of regional early warning systems for debris flows are based on critical rainfall thresholds. However, these systems are affected by large spatial-temporal uncertainties due to the inadequate number and distribution of rain gauges. In addition, rainfall analysis alone does not explain the dynamics of sediment fluxes at the catchment scale: short-term variations in the sediment sources strongly influence the triggering of debris flows, even in catchments characterized by unlimited sediment supply.

In this work, we present multi-parametric observations of debris flows at the headwaters of the Gadria catchment (eastern Italian Alps). In 2018, we installed a monitoring network composed of geophones, three soil moisture probes, one tensiometer and two rain-triggered video cameras in a 30-m wide steep channel located at about 2200 m a.s.l. Most sensors lie on the lateral ridges of this channel, except for the tensiometer and the soil moisture probes that are installed in the channel bed at different depths. This network recorded four flow events in two years, two of which occurred at night. Specifically, the debris flows that occurred on 21 July 2018 and 26 July 2019 produced remarkable geomorphic changes in the monitored channel, with up to 1-m deep erosion. For all events, we measured peak values of soil water content that are far from saturation (<0.25 at -20 cm, <0.15 at -40 cm, <0.1 at -60 cm). We derived the time of occurrence and the duration of these events from the analysis of the seismic signals. Combining these pieces of information with data gathered at the monitoring station located about 2 km downstream, we could determine the flow kinematics along the main channel.
These results, although still preliminary, show the relevance of a multi-parametric detection of debris-flow initiation processes and may have valuable implications for risk management. Alarm systems for debris flows are becoming more and more attractive due the continuous development of compact and low-cost distributed sensor networks. The main challenge for operational alarm systems is the short lead-time, which is few tens of seconds for closing a transportation route or tens of minutes for evacuating settlements. Lead-time would significantly increase installing a detection system in the upper part of a catchment, where the debris flow initiates. The combination of hydro-meteorological monitoring in the source areas and seismic detection of channelized flows may be a reliable approach for developing an integrated early warning - alarm system.