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Hydro-meteorological trigger conditions of torrential flows in the Austrian Alps

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Introduction

The occurrence of debris flows is mostly associated with intensive rainfall events of short duration (convective rainfall) or long lasting rainfall. In some cases snow melt may be a factor (Mostbauer et al. 2018). The prediction of the initiation of such events based on critical rainfall (e.g. intensity-duration thresholds) is complicated by two main limitations. First, there are large uncertainties with measurement of the temporal and spatial distribution of rainfall in small alpine watersheds. Secondly, the disposition of a torrential watershed to develop a debris flow may vary over time. This variable disposition (Kienholz 1995) can be connected to the hydrological state of a catchment, to sediment availability, or land cover changes, e.g. after a wildfire. In this contribution we investigate the hydro-meteorological trigger conditions of debris flows in the Austrian Alps and how they differ to that of fluvial floods. We additionally assess whether there are some topographic effects that influence the critical initiation conditions.

Methods

We developed a semi-distributed, process-based rainfall-runoff model for six regions in Austria, ranging from high-alpine environments to pre-alpine watersheds, for which long time series of rainfall and runoff measurements are available and debris flows and fluvial floods occurred in the sub-watersheds. The modelling period for the six regions ranged from 46 to 71 years, including 3 to 43 days were debris flows were observed and 3 to 22 days were fluvial floods were observed. The model was run on a daily time-scale. Hence we analysed the hydrological system state on days were debris flow and fluvial floods were observed and compared it to the days were no event was observed. The hydrologic model includes several storage components that represent snow and glaciers, unsaturated soil, interception, as well as fast and slow responding system components. Within a region different precipitation and elevation zones were modelled separately on a daily basis. For model calibration a likelihood-based method was used to derive posterior distributions of 43 calibration parameters. A detailed description of the model and uncertainty assessment can be found in Prenner et al. (2018; 2019). For better representation of the different trigger conditions that can lead to torrential events we ex-post differentiate between the trigger

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type long-lasting rainfall events (LLR), short-duration storms (SDS), and snow melt (SM). Hydrological and meteorological data to calibrate and run the model were derived from public sources. Topographic characteristics of sub-catchments were debris flows were observed, were derived from a 10 x 10 m digital elevation model.

Outcomes

We find subtle differences between critical trigger conditions of debris flows and fluvial floods, which manifest mainly for long-lasting rainfall events. Measured precipitation and antecedent moisture conditions are significantly different between trigger types. Hydro-meteorological parameter values also vary between regions, however, show a similar temporal pattern. For example, a short-duration rainfall trigger tends to have a negative gradient of soil moisture on the days before the event occurs, while debris-flow initiation in the course of long-lasting rainfall is associated with a continuous build-up of soil moisture. We have no data to assess whether these different trigger conditions are related to different initiation mechanisms (e.g. channel bed erosion vs. slope instability). On a regional scale, there is evidence that events triggered by short-duration storms are independent of aspect, but tend to happen more often in smaller and steeper catchments.

The main outcome of our study is that the initiation of torrential processes is associated with different hydro-meteorological trigger types. Taking into account the variations of hydrological history of a watershed improves the predictive power of forecasting tools. However, hydro-meteorological information and topography are not sufficient to predict whether a debris flow or a fluvial flood will occur. For that probably more detailed information on geomorphologic disposition (e.g. sediment availability in the channel) is needed.

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