Abstract

Landslides are frequent natural hazards in rugged terrain, when the resisting frictional force of the surface of rupture yields to the gravitational force. These forces are functions of geological and morphological factors, such as angle of internal friction, local slope gradient or curvature, which remain static over hundreds of years; whereas more dynamic triggering events, such as rainfall and earthquakes, compromise the force balance by temporarily reducing resisting forces or adding transient loads. This thesis investigates landslide distribution and orientation due to landslide triggers (e.g. rainfall) at different scales (6–$4 \cdot 10^5$ km^2); and aims to link rainfall movement with the landslide distribution. It additionally explores the local impacts of the extreme rainstorms on landsliding and the role of precursory stability conditions that could be induced by an earlier trigger, such as an earthquake.

Extreme rainfall is a common landslide trigger. Although several studies assessed rainfall intensity and duration to study the distribution of thus triggered landslides, only a few case studies quantified spatial rainfall patterns (i.e. orographic effect). Quantifying the regional trajectories of extreme rainfall could aid predicting landslide prone regions in Japan. To this end, I combined a non-linear correlation metric, namely event synchronization, and radial statistics to assess the general pattern of extreme rainfall tracks over distances of hundreds of kilometers using satellite based rainfall estimates. Results showed that, although the increase in rainfall intensity and duration positively correlates with landslide occurrence, the trajectories of typhoons and frontal storms were insufficient to explain landslide distribution in Japan. Extreme rainfall trajectories inclined northwestwards and were concentrated along some certain locations, such as coastlines of southern Japan, which was unnoticed in the landslide distribution of about 5000 rainfall-triggered landslides. These landslides seemed to respond to the mean annual rainfall rates.

Above mentioned findings suggest further investigation on a more local scale to better understand the mechanistic response of landscape to extreme rainfall in terms of landslides. On May 2016 intense rainfall struck southern Germany triggering high waters and landslides. The highest damage was reported at the Braunsbach, which is located on the tributary-mouth fan formed by the Orlacher Bach. Orlacher Bach is a ~3 km long creek that drains a catchment of about ~6 km^2. I visited this catchment in June 2016 and mapped 48 landslides along the creek. Such high landslide activity was not reported in the nearby catchments within ~3300 km^2, despite similar rainfall intensity and duration based on weather radar estimates. My hypothesis was that several landslides were triggered by rainfall-triggered flash floods that undercut hillslope toes along the Orlacher Bach. I found that morphometric features such as slope and curvature play an important role in landslide distribution on this micro scale study site ($<$~10 km^2). In addition, the high number of landslides along the Orlacher Bach could also be boosted by accumulated damages on hillslopes due karst weathering over longer time scales.

Precursory damages on hillslopes could also be induced by past triggering events that effect landscape evolution, but this interaction is hard to assess independently from the latest trigger. For example, an earthquake might influence the evolution of a landscape decades long, besides its direct impacts, such as landslides that follow the earthquake. Here I studied the consequences of the 2016 Kumamoto Earthquake (M$_W$ 7.1) that triggered some 1500 landslides in an area of ~4000 km^2 in central Kyushu, Japan. Topography, i.e. local slope and curvature, both amplified and attenuated seismic waves, thus controlling the failure mechanism of those landslides (e.g. progressive). I found that topography fails in explaining the distribution and the preferred orientation of the landslides after the earthquake; instead the landslides were concentrated around the northeast of the rupture area and faced mostly normal to the rupture plane. This preferred location of the landslides was dominated mainly by the directivity effect of the strike-slip earthquake, which is the propagation of wave energy along the fault in the rupture direction; whereas amplitude variations of the seismic radiation altered the preferred orientation. I suspect that the earthquake directivity and the asymmetry of seismic radiation damaged hillslopes at those preferred locations increasing landslide susceptibility. Hence a future weak triggering event, e.g. scattered rainfall, could further trigger landslides at those damaged hillslopes.