Geophysical Research Abstracts
Vol. 21, EGU2019-10707-1, 2019
EGU General Assembly 2019

An integrated water balance approach to analyze rainfall driven landslides

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Landslides are major hazards to human life and business. In Europe alone, landslides cost 1370 lives in the period 1995–2004 and caused an average economic loss of 4.7 billion Euros per year [Haque et al., 2016].

Landslide susceptibility maps are traditionally based on predisposing factors, such as strong relief, tectonic activity, vegetation characteristics, geomorphology and hydrology. Classification of landslide susceptibility is typically based on heuristics, either relying on expert analysis or trained on previous events, weighting predisposing factors.

The increased frequency of data acquisitions from satellite remote sensing platforms can complement existing landslide inventories and terrestrial monitoring activities and provides opportunities to improve susceptibility estimates to an up-to-date hazard analysis.

It is recognized that hillslope stability is strongly influenced by hydrology [Bogaard and Greco, 2016], and velocity changes in landslides have been shown to be directly coupled to hydrological changes [Benoit et al., 2015]. Our proposed solution is to exploit this correlation between contributing and resulting factors based on a simple *bucket model*.

A bucket model is a hydrologic water balance that can be compiled at various spatial scales. Water storage in the soil is key in rainfall driven landslides. The change in (ground)water storage over time ($\frac{dS}{dt}$) is the resultant of precipitation (P) input and evaporation (E) and discharge (Q) output fluxes: $\frac{dS}{dt} = P - E - Q$.

Aim is an integrated approach for data analysis, at different spatial scales, trained by multivariate pattern analysis of past events. Given enough of these past patterns prediction of future events is feasible, even with a limited inventory of past events.

Data that will be used as input in such water balance is daily available at kilometer resolution on a global scale. Snow and temperature data are provided by ESA DUE GlobSnow and GlobTemperature programs and are to be superseded by their ESA CCI equivalents; evaporation and transpiration by the Global Land Evaporation Amsterdam Model (GLEAM) and NASA GPM precipitation data provides precipitation at 30 minute resolution. On a local scale, gauges provide discharge while weather stations provide local precipitation and temperature measurements.

Deformation rates providing information on the behaviour of the landslide under varying hydrologic conditions are estimated from Sentinel-1 InSAR analysis, terrestrial total station and laser scanning measurements. Due to the dynamic character of the model, resources are easily replaced or complemented by other data sets.

Data abundance comes at the cost of intensive data handling. To analyze and exploit the correlation in the different variables provided, all have to be brought to the same reference frame both in space and time. All data sources are described in a unified manner so that on demand a new, compound, data set can now be generated, carrying all variables in the same reference frame.

This work is part of the H2020 OPERANDUM project on the mitigation of hydro-meteorological phenomena in risk-prone areas using nature-based solutions. The concept is tested in the Tuxer Alps, Austria on a landslide of 2×3 kilometer. The method developed is intended to be applicable to all geohazards linked to hydro-meteorological events, including floods and droughts, and is generic in nature.