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Resolution matters: numerical analysis of the effect of subgrid heterogeneities on soil hydrology and slope stability with a physically based hydrological model

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In Switzerland most of the natural hazards are triggered by precipitation, but the soil status prior to the rainfall event is also an important factor. That is true, for example, for floods and landslides, which were responsible collectively for a loss of nearly 8000 million Euros between 1972 and 2007 (Hilker et al., 2009, NHESS). Similar levels of economic losses were reported for other alpine regions.
The water table height and soil saturation necessary to predict the occurrence of these natural hazards accurately are typically calculated employing hydrological models. While in some cases high resolution small scale models are developed for specific case studies, there is also a need for regional scale warning system which provide a first order estimate of the vulnerability across the country (Staehli et al., 2015, NHESS). These coarse scale models face problems of subgrid variability in topography and soil water dynamics and their effects on slope stability may be complex.

Here we use synthetic numerical experiments to quantify the effect of heterogeneities within a cell of the size typically used for regional hydrological applications. We use the hydrological model ParFlow-CLM (e.g. Maxwell and Miller, 2009, J. Hydrometeorol.), which is an integrated, fully coupled, physically based model, which solves water and energy budgets, surface and subsurface flows. The reference simulation is represented by a domain of 400*400 m without any heterogeneities within. This setup corresponds to the information content of a cell of a regional scale model. Results are compared to those where subgrid heterogeneities in slope (creating a v-shape domain) or soil layering (permeability contrasts or soil thickness) are added with cell resolutions 20*20 m. These experiments aim to provide insights on what the under/over estimation of water pressure and soil saturation could be when using coarser resolutions which average out heterogeneities.

Different climates and soil properties are also investigated by comparing the results with the climatic forcing and soil properties for the site Napf in Switzerland (wet temperate) and Niwot in Colorado (semiarid). Climatic forcing is found to be the main factor controlling dynamics and seasonalities of the snowpack and evapotranspiration, while soil properties influence greatly runoff generation mechanisms as well as the timing and intensity of runoff. All these conditions lead to very different scenarios in terms of calculated soil water pressure.

Finally, in order to quantify the effect of potential over/under estimation of soil water pressure and soil saturation for one possible application, the slope stability of the domains is calculated choosing the most critical point (where highest pressures are developed) following a simple infinite slope model balancing soil strength and applied shear stress. The biggest differences are observed between flat domains and those that have any magnitude of side slope, where the factor of safety may indicate slope failure locally when subgrid variability is included

These results provide useful information on the potential errors when utilizing a regional hydrological model with "coarse" resolution, which is particularly critical when the ultimate objective is predicting flooding and landsliding potential.