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Nonlinear effects of microtopography on macroscopic rainfall-runoff partitioning a the hillslope scale: a modelling study

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The quantitative description and prediction of hydrological response of hillslopes or hillslope-scale catchments to rainfall events is becoming evermore relevant. At the hillslope scale, the onset of runoff and the overall rainfall-runoff transformation are controlled by multiple interacting small-scale processes, that, when acting together produce a response described in terms of hydrological variables well-defined at the catchment and hillslope scales.

We hypothesize that small scale features such microtopography of the land surface will will govern large scale signatures of temporal runoff evolution. This can be tested directly by numerical modelling of well-defined surface geometries and adequate process description. It requires a modelling approach consistent with fundamental fluid mechanics, well-designed numerical methods, and computational efficiency.

In this work, an idealized rectangular domain representing a hillslope with an idealized 2D sinusoidal microtopography is studied by simulating surface water redistribution by means of a 2D diffusive-wave (zero-inertia) shallow water model. By studying more than 500 surfaces and performing extensive sensitivity analysis forced by a single rainfall pulse, the dependency of characteristic hydrological responses to microtopographical properties was assessed. Despite of the simplicity of periodic surface and the rain event, results indicate complex surface flow dynamics during the onset of runoff observed at the macro and micro scales. Macro scale regimes were defined in terms of characteristics hydrograph shapes and those were related to surface geometry. The reference regime was defined for smooth topography and consisted of a simple hydrograph with smoothly rising and falling limbs with an intermediate steady state. In constrast, rough surface geometry yields stepwise rising limbs and shorter steady states. Furthermore, the increase in total infiltration over the whole domain relative to the smooth reference case shows a strong non-linear dependency on slope and the ratio of the characteristic wavelength and amplitude of microtopography.

The coupled analysis of spatial and hydrological results also suggests that the hydrological behaviour can be explained by the spatiotemporal variations triggered by surface connectivity.
This study significantly extents previous work on 1D domains, as our results reveal complexities that require 2D representation of the runoff processes.