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Effects of microtopography across spatial scales: studying hydrological response through high-resolution shallow-water modelling

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Microtopography is recognised as one of the morphological features which controls runoff generation, surface hydrodynamics, and surface runoff hydrological response. The spatial scales of microtopography are orders of magnitude smaller than typical hydrological domains such as hillslopes or catchments. The hydrodynamic response in the presence of microtopography is complex and its impact on hydrological behaviour is inherently a multiscale problem, influenced by a number of processes and features. In particular, the geometrical properties of microtopography, and the ponded volume in relation to rainfall volume play a role at the micro and meso scales, while the hydrological response at a larger “macro” scale depends on how large such spatial macroscale is: at sufficiently small scales, the hydrological response is ill-defined; at very large scales, microtopography may not be relevant. Yet, at some intermediate scales, the hydrological dynamics can be strongly dominated by microtopography.

In this work, a state-of-the-art, high-performance shallow water solver is used to simulate rainfall-runoff processes on an idealised catchment, at a spatial resolution which explicitly and completely resolves microtopography. For simplicity, microtopography is modelled as a 2D sine wave, which is superimposed on a planar hillslope. A four-dimensional parameter space is explored, defined by different slopes, different amplitudes and wavelengths for the microtopography, and different rainfall events. The large parameter space, together with the high resolution and the inherent cost of the solver result in a very large computational cost. In consequence, we implement SERGHEI, a parallelised, high-performance shallow water equations solver based on the Kokkos programming framework. SERGHEI enables computations on heterogeneous systems and multiple graphics processor units (GPU), which allows to address very large computational studies such as this one.

Rainfall-runoff-infiltration partitioning is evaluated in terms of runoff, infiltration and ponding volumes, as well as in terms of a contingency table of flooded surfaces for a reference smooth surface and a set of rough surfaces with microtopography. The results are compared both globally (for the entire domain) and in a spatially-distributed manner in order to assess at which spatial scales the hydrodynamic heterogeneity manifests itself as an emergent hydrological behaviour.

The preliminary results show a non-linear response of hydrological signatures to the different parameters, and a complex dependency across scales.