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# The role of topography and intra-annual rainfall variability in semi-arid vegetation self-organisation: a multi-scale modelling study

Daniel Caviedes-Voullième and Christoph Hinz
Chair of Hydrology, Brandenburg University of Technology, Cottbus, Germany (caviedes@b-tu.de)

Coevolution of hydrological and vegetation dynamics in semi-arid regions has been widely observed to result in vegetation self-organisation (VSO). Many hypothesis of VSO's underlying ecohydrological processes and feedbacks have been studied relying on mathematical models, which have been key to evaluate the sensitivity of ecohydrological systems to environmental factors and drivers. Although this ecohydrological coevolution is essentially multiscale, researchers have continued to be constrained by the simplicity of the models which are unable to cope with the multiscale, process-based complexity of fast-moving surface water over complex topographies driven by varying rainfall, during decade-to-century long VSO processes. This limitation has not allowed deep exploration of the role and sensitivity of key environmental factors such as topography and rainfall variability, and the lack of proper hydrodynamics still constrains adequate sediment transport modelling and its feedback effects on VSO. We hypothesize that the intra-storm water redistribution by surface runoff at the hillslope scale is strongly controlled by both topography and storm intensity and may control VSO. This requires for these environmental factors to be accurately represented in models and their their hydraulic and hydrological effects properly reflected.

This work provides the first systematic study of the effects of topography and intra-annual rainfall distributions on vegetation band formation at the hillslope scale. Simulations were performed with a physically-based numerical model solving the Zero-Inertia approximation to the shallow water equations for surface flow coupled to the HilleRisLambers-Rietkerk vegetation model, allowing to explicitly represent arbitrary topography. An idealized study of ecohydrological evolution over 30 years was performed, solving with a temporal resolution in the seconds scale. Plane, convex and convex hillslope topologies with different slopes were used, while forcing the model with different annual rainfalls along a semi-arid rainfall gradient, with discrete events of different frequencies. We describe results in terms of evolution of total biomass, hydrological water balance, and of the spatial properties of banded vegetation.

Results show that both topography and intra-annual rainfall distribution can play a shaping and governing role in VSO by controlling surface water redistribution and the hydrologic water balance. Increasing slopes favours runoff over infiltration, reducing the available water for vegetation and resulting in different evolutions of vegetation band geometry and band migration. Hillslope topology plays a strong role in the internal water redistribution of the system. Plane and convex surfaces behave similarly, but concave surfaces exhibit a different ecohydrological behaviour, despite the very small topological differences. Different intra-annual rainfall distributions result in different rainfall intensities for the same total annual rainfall which strongly affect the band formation and evolution process: higher intensities lead to less available water, to which vegetation adapts by spatially clustering in bands with different geometrical properties. The study also shows that it is computationally feasible (a few hours runtime) to perform decade-to-century long simulations of these systems with physically-based numerical models paving the way to simulate natural systems with arbitrary topography and high-resolution rainfall data, and is a first step in introducing physically-based sediment transport processes and feedbacks in these studies.