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Exploring the effects of rainfall variability on banded vegetation

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Vegetation self-organisation in water-limited ecosystems in semi-arid climates has been studied by means of numerical simulation using a set of reaction-diffusion-equations. The predominant approach in such studies, in particular relating to banded vegetation on slopes, has been to study the long-term steady ecohydrological tates on periodic domains forced by steady rainfall. This default modelling setup does not account for the fact that on a hillslope a net runoff loss may exist at the outlet. Moreover, such runoff loss is modulated by rainfall intensity, i.e., increasing rainfall intensity is likely to favour runoff over infiltration, and therefore affect the banded vegetation formation. Additionally, different inter-storm dry periods prompt different responses from the vegetation. One of the properties of semi-arid climates is a highly intermittent and variable precipitation regime, quite often with a few intense events and a larger number of very mild events. Additionally ecohydrological theory recognises that dryland ecosystems are in a quasi-permanent transient condition, exhibiting non-linear and far-from equilibrium responses to boundary conditions and forcings. The mismatch between the default modelling approach and the properties of rainfall in such systems calls for further complexity in the models and in the forcing.

We explore the possible effects that particular rainfall properties can have in banded vegetation dynamics. We solve the well-known Rietkerk model together with a zero-inertia approximation of the shallow-water equations for surface flow. A non-periodic domain with an outlet, i.e., a 2D hillslope with a constant slope is used. We perform simulations forced by a set of variations of idealised temporal distributions of rainfall throughout a year. The reference distribution is a periodic signal of constant intensity storms of a single day, separated by dryspells of equal duration. The total annual rainfall was selected as 270 mm, in the range of semi-arid climates. This annual signal is repeated during the entire simulation. Non-periodic rainfall signals were generated by randomising a single rainfall property but ensuring the same annual rainfall. Randomisations of the inter-storm dryspell duration, the storm duration, and the storm intensity were explored. Although this results also in idealised rainfall signals, it allows for systematic analysis of each property.

The banded patterns are assessed both in terms of global signatures (biomass, vegetation cover), spatial properties (number of bands, wavelength and bandwidth), and dynamics (migration

velocity of the bands). Our results clearly show qualitatively and quantitatively that the simulated banded vegetation has a strong response to rainfall variability. Moreover, the results also show a high sensitivity to the particular succession of events, e.g., a succession of longer than average dryspells can throw the system away from equilibrium. High sensitivity is also observed to the timing of certain individual events. The system responds differently to events which happen early on in the development, or later, when the system is near equilibrium. The simulated response of the system are arguably too volatile, suggesting that improvements in the vegetation model parametrisation and formulation are warranted to better represent dynamics and allow for stability and resilience studies.