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Coevolution in the critical zone: the key role of fast hydrologic processes

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Feedback effects between hydrology, vegetation and erosion processes are pervasive across landscapes. These tight interactions lead to the coevolution of landscape patterns that modulate landform shape and regulate many other critical zone processes. We study these feedbacks and interactions using simulations from landform evolution models that account for the effect (and feedbacks) of spatially and temporally varying hydrologic pathways and vegetation over landscapes displaying a variety of vegetation patterns.

We first present results from a landscape evolution modelling framework, that accounts for a comprehensive representation of hydrology and vegetation, including the effect of various vegetation pools on erosion processes. The model includes interacting modules for hydrology, dynamic vegetation, biomass pools partition, and landform evolution. Our simulations indicate that each of the biomass pools provides a specific erosion protection mechanism at a different time of the year. As rainfall events and the resulting vegetation growth and protection are asynchronous, the maximum values of erosion are associated with runoff at the beginning of the rainy season when vegetation protection is not as its maximum. These results show how rapid hydrological processes affecting vegetation have long term implications for landform development. Results for a Eucalyptus savanna landscape study site in the Northern Territory (Australia) showed that models that do not account for the vegetation dynamics can result in prediction errors of up to 80%.

We also present simulations of the coevolution of landforms and vegetation patterns in selected sites with patchy Acacia Aneura (Mulga) vegetation. These sites display a sparse vegetation cover and strong patterns of surface water redistribution, with runoff sources located in the bare areas and sinks in the vegetation patches. This effect triggers high spatial variability of erosion/deposition rates that affects the evolving topography and induces feedbacks that shape the dynamic vegetation patterns. We run simulations using rainfall, vegetation and erosion data, and vegetation parameters previously calibrated for Mulga sites in the Northern territory. We further investigate the effect of alterations in hydrologic connectivity induced by climate change and/or anthropogenic activities, which affect water and sediment redistribution and can be linked to loss of resources leading to degradation. We find that an increase in hydrologic connectivity can trigger changes in vegetation patterns inducing feedbacks with landforms leading to degraded states. These transitions display non-linear behaviour and, in some cases, can lead to thresholds with an abrupt reduction in productivity. Critical implications for management and restoration are discussed.