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Influence of vegetation in fluvial morphodynamics: an analytical approach

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We present the results of the linear stability analysis of coupled ecomorphodynamic equations. As classically done in morphodynamics, flow dynamics is described by the shallow water equations, and is coupled to sediment dynamics (Exner equation, with closure relation for the sediment transport). We however introduce in addition an equation for the evolution of the biomass, which we couple to the morphodynamic equations. We first model the influence of the biomass on the flow via a Chezy coefficient depending both on bed roughness and on the roughness introduced by idealized vegetation. The flow produces as negative feedback a biomass mortality term.

We first perform the stability analysis for one-dimensional ecomorphodynamic equations. We find that for realistic values of the sediment transport parameter vegetation plays the central role in determining the wavelength of the longitudinal patterns. Bed topography essentially adjusts to the spatial periodicity fixed by vegetation. We then repeat this analysis in a two-dimensional setup, for which the system may evolve either towards alternate bars or multiple bars. The analysis allows identifying domains of the parameter space where the instability results from the coupled flow-sediment dynamics and is also observed without the biomass. In other regions of the parameter space, instability is observed for both a fixed and a mobile bed setup: it can therefore clearly be ascribed to the coupled flow-vegetation dynamics. Interestingly, the two regions are connected and one may observe a real interplay between flow, sediment and vegetation dynamics to produce patterns.

Our analysis is performed for a simplified ecomorphodynamic model in order to be able to obtain generic analytical results. We discuss under which conditions the results obtained for a constant flow can be generalized to the situation with a non-constant hydrograph. We considered only the couplings between flow and vegetation in the form of roughness changes and biomass mortality, in order to be able to systematically explore the parameter space. The model can however directly be extended to account for other couplings (e.g. flow deflection by vegetation or root-induced increased sediment stability).