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Theory and empirical evidence for the irregularity of self-organized vegetation patterns

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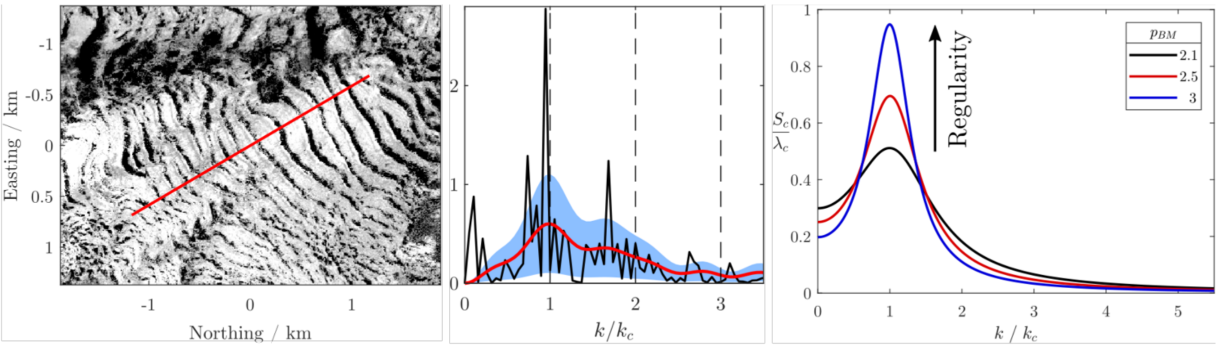
In arid environments, vegetation tends to self-organize into patches separated by bare soil. This is necessitated by the lack of water for sustaining a continuous vegetation cover and facilitated by the attraction of water from barren interpatch areas by the vegetation. This process is a positive feedback which introduces spatially heterogeneity into otherwise homogeneous environments, characterised by regular patterns. These patterns are typically considered to be periodic and distinguished on hand of their wavelength. Such patterns have so far been studied with numerical models which generate periodic patterns in homogeneous environments. However, environments are rarely homogeneous, as topography and soil-hydraulic properties vary in space. This raises the questions to which degree heterogeneity of vegetation is self-organized or imposed by the environment, and how environmental heterogeneity interacts with the self-organization process. In contrast to the persisting conceptual model of periodic patterns, natural vegetation exhibit a high degree of irregularity. Several studies have linked this irregularity to heterogeneity in the environment, but a comprehensive theory for analysing the irregularity has not yet been established. Furthermore remains the extend of irregularity unexplored on a global scale. To fill this gap, we, demonstrate empirically the global prevalence of irregularity in vegetation patterns and find that natural vegetation patterns are stochastic, rather than periodic. We then propose a stochastic framework to conceptually describe and measure the regularity, based on the spectral density of the patterns. In addition to the dominant wavelength, measuring the spatial scale, it reveals a novel parameter, measuring the regularity. The parameter is determined by the correlation structure and discriminates gradually between the limit cases of periodicity and white noise. Applied to natural and computer-generated patterns, we find that the former are highly irregular, while the latter are close to periodic. We reproduce the stochasticity of patterns with numerical models by introducing spatial heterogeneity of the model coefficients. We provide a fresh look at the nature of vegetations patterns and present a comprehensive theory for a more holistic understanding of self-organized systems.



a) Banded vegetation pattern, b) its spectral density, c) spectral density model.