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Comment on "Multiple equilibrium states and the abrupt transitions in a dynamical system of soil water interacting with vegetation" by X. Zeng et al.

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[1] *Zeng et al.* [2004] modeled two stable equilibrium states (bistability) and the abrupt boundaries of vegetation in semi-arid grassland ecosystems. The bistability in their model is due to a positive feedback between increased plant biomass and reduced evaporation. Therefore, they claim that vegetation boundaries are abrupt even when the water availability decreases smoothly along a gradient. In this comment we stress that well-known spatial processes lead to spatial pattern formation and changing parameter regions. Furthermore we argue that the model results of *Zeng et al.* [2004] cannot be interpreted as abrupt vegetation boundaries.

[3] Horizontal homogeneous models, like the single vertical column of *Zeng et al.* [2004], are helpful to understand bistability in homogeneous or well-mixed ecosystems [*Scheffer et al.*, 2001]. However, semi-arid ecosystems are spatially extensive and heterogeneous. It has been shown that positive feedbacks between plant biomass and water infiltration rate, reduced evaporation, and increased transpiration due to extended root systems trigger spatial processes such as run-off and lateral soil water movement [*Klausmeier*, 1999; *von Hardenberg et al.*, 2001; *Rietkerk et al.*, 2002]. Therefore, these ecosystems typically require an understanding of the relation between soil-vegetation feedback and spatial scale. In a review of *Rietkerk et al.* [2004] it has been demonstrated that increased water scarcity in arid ecosystems leads to emerging self-organized vegetation patchiness. Vegetation states include homogeneous cover, gaps, labyrinths or stripes and spots depending on different strength of the feedbacks caused by water availability. This implies that vegetation boundaries are not necessarily abrupt when water availability is decreased smoothly along a gradient, but may go through a diversity of vegetation patterns instead [*von Hardenberg et al.*, 2001; *Rietkerk et al.*, 2002, 2004] (Figure 1). Additionally, and following from this, we stress that the outcome of the model of *Zeng et al.* [2004] cannot be interpreted as abrupt vegetation boundaries, as it starts from the a-priori assumption of horizontal homogeneity.

[4] Furthermore, the parameter region of bistability found by *Zeng et al.* [2004] will change if spatial processes were included. For example, vegetation may still persist in self-organized patches for precipitation regimes where *Zeng et al.* [2004] already predict bare soil [cf. *Lejeune et al.*, 2002, 2004; *Rietkerk et al.*, 2004] (Figure 2). These self-organized patches coincide with higher soil moistures as compared to bare soil. Therefore, this will have an impact on precipitation [cf. *Koster et al.*, 2004; *Zeng et al.*, 1999], although the extent of the effect on soil-vegetation-atmosphere interactions remains a challenge for further research. For example, the new proposed model of *Zeng et al.* [2004] could be extended by incorporating spatial processes and embedded in the state of the art literature. Further key questions concern how the outcome of such model is affected by seasonality in rainfall and local geological and soil differences. Another aspect that could be further analyzed is the possible asymmetry of collapsing and recovery time scales.

Figure 1. Field observations of striped patterns of bushy vegetation in Niger. (© 2002 University of Chicago.) See color version of this figure in the HTML.

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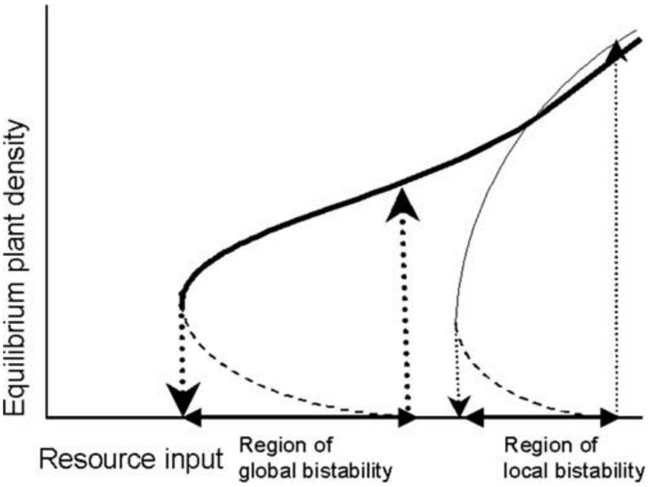

Figure 2. Conceptual model of regions of global bistability (with spatial processes) and local bistability (without spatial processes) [cf. *Rietkerk et al.*, 2004] simplified from results of *Lejeune et al.* [2002], showing that self-organized patchiness (thick line) may survive into regions where homogeneous plant cover (thin line) would go extinct. Thick and thin solid lines refer to mean global equilibrium biomass densities of vegetation patterns and local equilibrium biomass without spatial processes respectively. Dotted lines refer to unstable equilibrium states.

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