Reply to comment by Dekker and Rietkerk on "Multiple equilibrium states and the abrupt transitions in a dynamical system of soil water interacting with vegetation"

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[1] *Dekker and Rietkerk* [2005] (hereinafter referred to as DR) raise some valid points regarding our paper "Multiple equilibrium states and the abrupt transitions in a dynamical system of soil water interacting with vegetation" [*Zeng et al.*, 2004] (hereinafter referred to as XZ). We appreciate the opportunity to clarify these issues here and hope this dialogue (between scientists working on horizontal interaction and spatial patterns and those who are more interested in the area-averaged land-atmosphere interactions) will shed some new lights on the overall land modeling over arid and semiarid regions.

[2] DR argued that XZ ignored well-known spatial processes, leading to spatial pattern formation, no abrupt boundaries, and dramatically changing parameter regions. As a single column model, by definition, horizontal interactions cannot be explicitly included and spatial patterns cannot be produced in XZ. However, this does not mean that the area-averaged effects of these spatial patterns are completely ignored. In fact, horizontal heterogeneity is included in XZ by separately considering processes (e.g., evaporation, transpiration, runoff) over the vegetated and non-vegetated areas in a single column. The use of average soil water over the column also implies an (instantaneous) horizontal water exchange between these two areas. In contrast, models on spatial patterns as reviewed by *Rietkerk et al.* [2004] would divide this single column into numerous small cells. While the horizontal interaction among different cells is considered in these models, each cell is assumed to be uniformly covered by vegetation (i.e., without considering bare soil fraction).

[3] Different mechanisms have been proposed to explain the self-organized spatial patterns, as summarized by *Rietkerk et al.* [2004]. The essence of all these mechanisms is that water is more concentrated into patches of vegetation due to spatial interactions over arid and semiarid regions. Since our single column model contains only the soil water averaged over vegetated and non-vegetated areas, the above effect can be largely represented by the increase of the exponential coefficient in the biomass growth dependence on soil water (i.e., XZ, ε_g' in equation (4)). Indeed, Figure 1 shows that, as ε_g' increases, the parameter regime of bistability between μ_1 and μ_2 shifts towards left, in agreement with Figure 2 of DR. Detailed discussion of the sensitivity of the parameter regime of bistability to all model parameters is given by *Zeng et al.* [2005]. Further, in Figure 1 vegetated states at different ε_g' do not converge to the same state, in agreement with *van de Koppel and Rietkerk* [2004]. In contrast, it is unclear how DR draw their Figure 2 where the vegetated states with or without spatial interactions intercept with each other at a higher resource input, which is inconsistent with *van de Koppel and Rietkerk* [2004] and Figure 1 here.

[4] We also agree with DR that, visually, vegetation boundaries are not abrupt but go through a diversity of vegetation patterns instead over arid and semiarid regions, and we regret that this point was not explicitly stated in XZ. However, the abrupt change was discussed in terms of biomass in XZ and other references cited in DR. For instance, Figure 1 shows that a small perturbation near the unstable equilibrium state or a small variation in moisture index near the critical points μ_1 and μ_2 may lead to a desert or vegetated state. Note that the vegetated state in our single column model still contains non-vegetated area and may correspond to a particular spatial pattern [e.g., see *Rietkerk et al.*, 2004, Figure 3]. Therefore, even though our model cannot predict specific spatial patterns, it can still predict vegetation boundaries in terms of biomass.

[5] In summary, while horizontal interactions and spatial patterns are not explicitly considered in XZ, their effect averaged over an area can be implicitly represented by the adjustment of model coefficients, and the results in XZ on abrupt boundaries in terms of biomass and parameter regimes remain correct.

[6] While the model in XZ emphasizes vertical interactions between vegetation and soil water (e.g., inclusion of wilted biomass that is very important over temperate grassland), other models as reviewed by *Rietkerk et al.* [2004]

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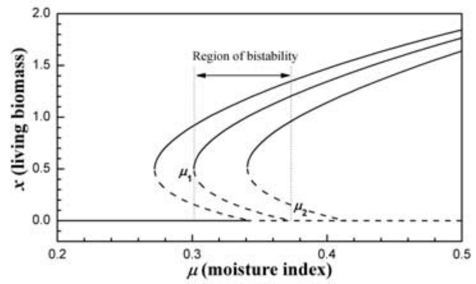

Figure 1. Sensitivity of the equilibrium states to ε'_g, the exponential coefficient of the growth dependence on the soil wetness (see XZ, equation (4)). From left to right, ε'_g = 1.2, 1.0, and 0.8. Solid and dash lines refer to the stable and unstable equilibrium states, respectively.

emphasize horizontal interactions and spatial patterns. Therefore, they are complementary to each other. All these models consider one vegetation type only and hence cannot simulate the competition and facilitation between vegetation types (e.g., grass versus shrub). Dynamic global vegetation models [e.g., *Bonan et al.*, 2003] do consider the interactions between vegetation types, and can be used to address the effect of other processes (e.g., atmospheric and oceanic variability) on vegetation-soil interactions and the effect of vegetation on the atmosphere. However, they don't explicitly consider horizontal interactions, just as XZ. Furthermore, the model in Bonan et al. does not seem to be able to produce bistability over arid and semiarid regions when water availability is changed smoothly. It is a challenge for the community to combine these models to form a comprehensive model that can efficiently predict spatial patterns, interaction between vegetation types, and abrupt transitions in biomass over arid and semiarid regions.

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