Climate-Vegetation Feedback*

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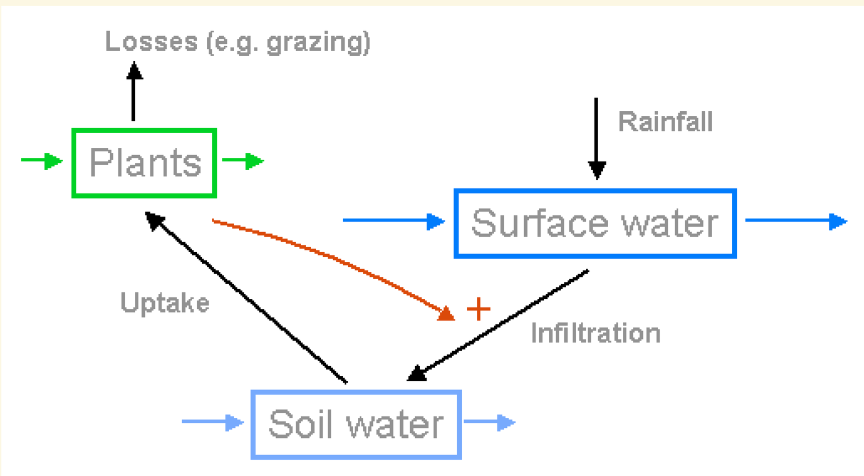
In this study we show how feedbacks at different scales interact and can affect both regional climate and microscale vegetation patterns. We will show that an accurate partitioning between evapotranspiration, runoff, and drainage can have significant influence on the terrestrial biosphere-atmosphere system.

Micro-Scale feedback

At microscale, additional positive feedbacks between hydrology and vegetation have been reported and have a large impact on vegetation distribution, density and spatial pattern formation (figure 1). Typical vegetation patterns of spots, labyrinths and gaps are shown in real world and modeled with spatial explicit models.

Fig 1: Infiltration feedback at microscale. Soil water availability is limited by low infiltration rate of the soil. Plants promote this infiltration (by rooting, preventing crusts) thereby having a positive feedback. Rainwater will run off to areas with high infiltration, thereby promoting vegetation growth.



Macro-Scale Feedback

Vegetation tends to be largely controlled by precipitation but in turn, vegetations affects local precipitation by modifying the atmospheric energy and water budget. In subtropical regions, like the Sahel, the monsoon from the ocean brings moist air to the continents. Figure 2 shows how advected moisture (Fin) is transported from the ocean to the Sahel. The precipitation (P) that falls on the Land Region comes from advected moisture (P_a) and local evaporative sources (P_l). Evapotranspiration (ET) comes from plants and bare soil.

At macroscale this land–atmosphere exchange constitutes a strong positive feedback between vegetation density and precipitation.

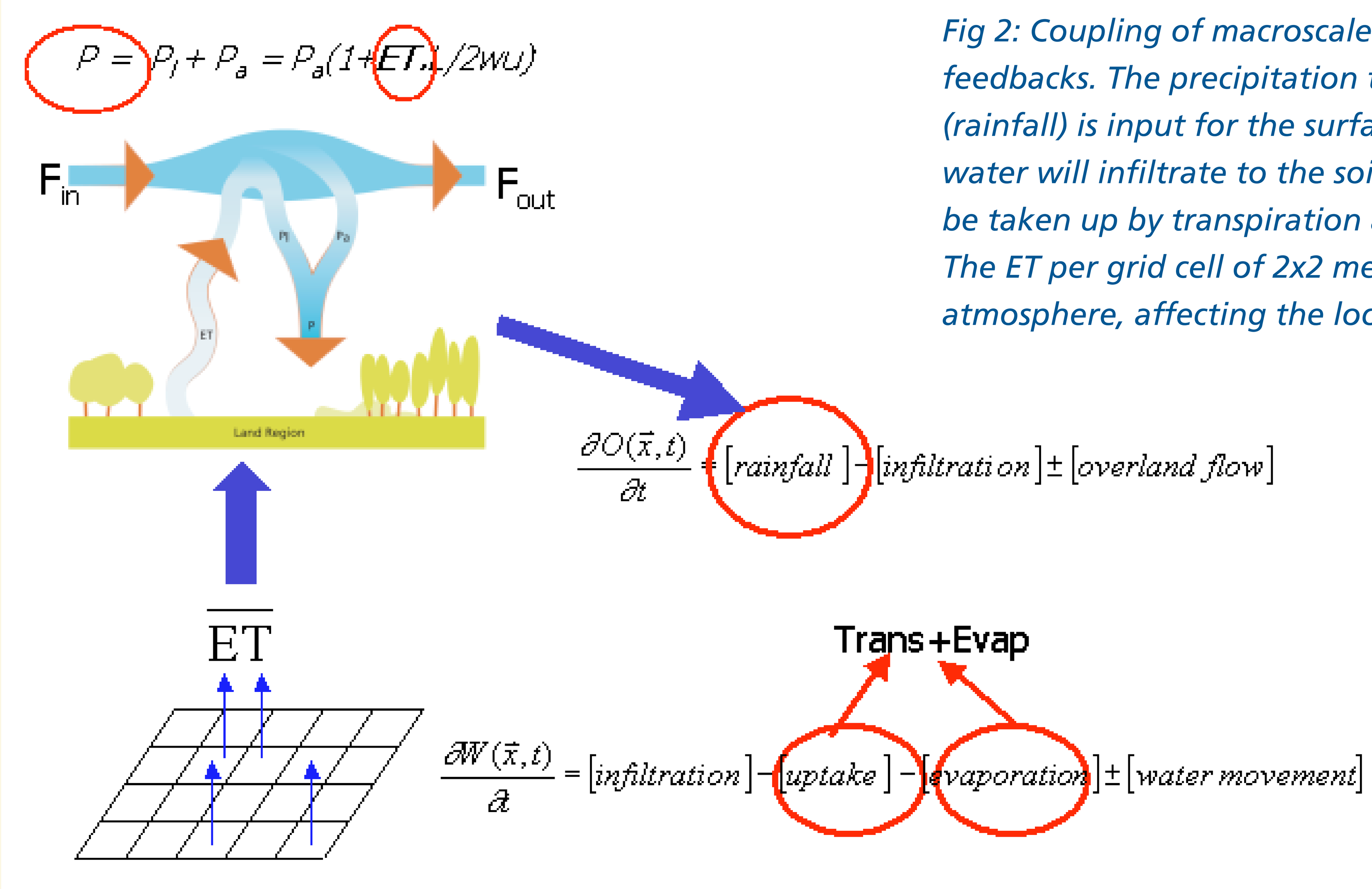
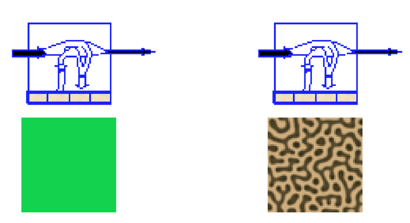


Fig 2: Coupling of macroscale and microscale feedbacks. The precipitation that falls on the land (rainfall) is input for the surface water (O). Surface water will infiltrate to the soil water (W), which can be taken up by transpiration and evaporation (ET). The ET per grid cell of 2x2 meter feedbacks to the atmosphere, affecting the local precipitation (P_l).

Coupling:

Because both macroscale and microscale positive feedbacks are present in the same region, it is reasonable to assume that these feedback mechanisms are connected. Therefore we developed and analysed a soil-vegetation-atmosphere model coupling large-scale evapotranspiration–precipitation feedback (Entekhabi et al. 1992) with a model of microscale vegetation–hydrology feedback (Rietkerk et al. 2002), figure 2. We now can switch on/off these feedbacks, resulting in two models (table 1).

Table 1: The PMod, with precipitation feedback and the IPMod, with both feedbacks.



Name	PMod *Entekhabi*	IPMod
Prec. fb	Yes	Yes
Infiltr. fb	No	Yes

Results

Figure 3 shows the bifurcation analysis of the IPMod (micro and macroscale) and PMod (only macroscale) models. PMod predicts a high homogenous plant biomass at high Pa. With decreasing P_a, plant biomass lineary decreases until it becomes extinct at ITCZ 0.42. IPMod predicts the same homogenous equilibrium at high Pa but it becomes unstable at point T. From T, non-homogenous equilibria occur illustrated by maximum and minimum plant biomass (thick lines), reflecting spatial vegetation patterns (from gaps, labyrinths to spots). With decreasing Pa, plants survive in spatial patterns until limit point LP_1 is reached, beyond which all values go extinct. Once extinct, P_a must be increased above limit point LP_2 before plants recover again. Figure 4 shows the relative precipitation feedback, i.e. precipitation feedback divided by the sum of P_a and P_l, for both models.

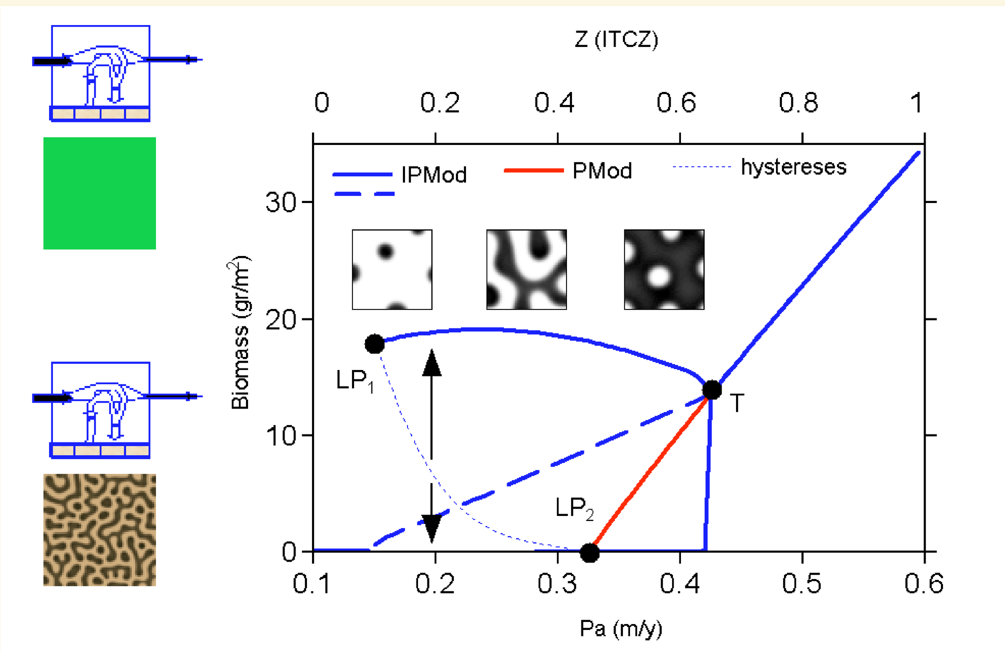


Fig 3: Bifurcation analyses of the IPMod and Pmod.

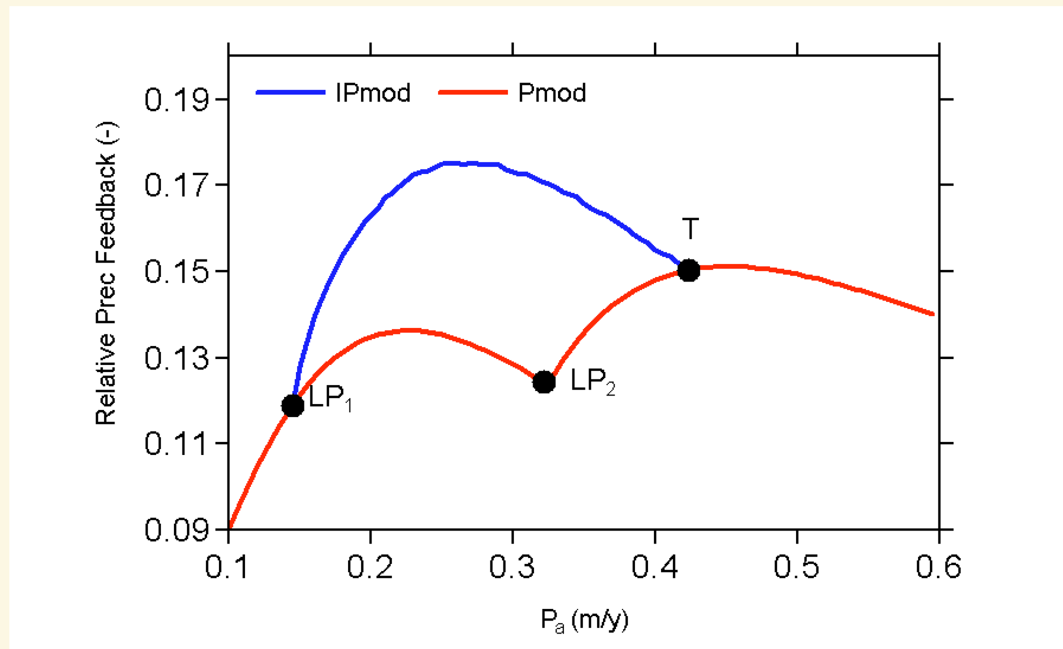


Fig 4: Relative precipition feedback (-) of IPMod and Pmod.

Conclusions

From our results, two important conclusions can be drawn: (1) it is important to account for spatially explicit vegetation dynamics at the microscale in climate models (the strength of the precipitation feedback increased up to 35% by accounting for these microscale dynamics); (2) studies on resilience of ecosystems to climate change should always be cast within a framework of possible large-scale atmospheric feedback mechanism (substantial changes in vegetation resilience resulted from incorporating macroscale precipitation feedback). Analysis of full-coupled modelling shows that both type of feedbacks markedly influence each other and that they should both be accounted for in climate change models.

Literature:

Entekhabi, D., Rodrigueziturbe, I. and Bras, R.L., 1992. Variability in Large-Scale Water-Balance with Land Surface Atmosphere Interaction. *Journal of Climate*, **5**(8): 798-813.

Rietkerk, M. et al., 2002. Self-organization of vegetation in arid ecosystems. *American Naturalist*, **160**(4): 524-530.

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