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Discussions

# *Interactive comment on* "HESS Opinions: A Planetary Boundary on Freshwater Use is Misleading" *by* Maik Heistermann

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I would like to thank Prof Savanije for his substantial and profound comments. So far in this interactive discussion, his contribution is the only one that actually and explicitely frames a mechanism through which changes in a basin's water balance could affect the water budget of far distant basins.

His argument is based on the process of moisture recycling, or, more specifically on a study by Van der Ent et al. (2010) which impressively demonstrates how large scale moisture fluxes (and thus precipitation) on land are sustained by land evapotranpiration, and that *"large parts of the world rely for 80 percent or more on moisture that has been recycled (sometimes several times) by evaporation from land."* This way, a regional decrease in land evapotranspiration, caused by an anthropogenic disturbance,



could potentially reduce the precipitation downwind the general atmospheric circulation. While Prof Savanije (in his comment) and Van der Ent et al. (2010) elaborate specifically on the potential effects of land use change, namely deforestation, we might want to generalise the perspective to any anthropogenic disturbance of a regions evaporative performance - including consumptive freshwater use. At this point, a couple of issues come to mind.

Deforestation, i. e. the anthropogenic replacement of forests by e. g. cropland, implies that regional land evaporation and, as a result, the effectiveness of the continental moisture recycling chain is reduced, so that downwind of the atmospheric moisture flux precipitation might decrease. Increasing consumptive freshwater use, however, implies an *increase* of land evaporation, and thus a potential intensification of moisture recycling (correct me if I'm wrong). So, should Europe and Russia boost consumptive water use in order to maintain water resources in northeast China? Of course, we will not follow up on such an exotic thought, and most likely, it will miss the point: consumptive blue water use is a dominant process in semi-arid regions. In such regions, the continental evaporation recycling ratio might indeed be high, but will the absolute moisture contribution to downwind regions, too?

Another question is at which point the mechanism of moisture recycling will become a *feedback mechanism* that, as suggested by Prof Savanije, could have irreversible effects. We have to be precise, though, in the definition of a feedback. Van der Ent et al. (2010) refer to the *"continental moisture feedback", or "positive feedback mechanism between continental evaporation and rainfall"*. In his short comment, Prof Savanije sees a *"negative feedback [of land use change] on terrestrial precipitation"* which is formally correct if we put it like e.g. "more deforestation causes less terrestrial precipitation". From a systems perspective, however, it could be more helpful to conceive it as a *positive* (destabilising/reinforcing) feedback such as "a decrease in forested area causes a decrease of moisture recycling/terrestrial precipitation and thus a further decrease in forested area", where you can consider *forested area* as some idealised land use

type with high evaporative performance *and* a high vulnerability to water stress. Such a *positive* feedback could be imagined to unravel on a regional or continental scale (see Fig. 1). Quite a number of authors have picked up that idea before and after Van der Ent et al. (2010), some of the most recent examples being e.g. Zemp et al. (2017) and Boers et al. (2017) on corresponding tipping points in the Amazon forest. Still, as Prof Svanjie already implied in his short comment, the role of local coupling and changes in the atmospheric circulation are yet to be understood. Accordingly, Goessling and Reick (2013) argued that *"moisture recycling estimates cannot consistently be used as reliable indicators for the sensitivity of precipitation to modified land-evaporation."*

With absolute certainty, however, I am right now operating beyond my area of expertise. This is why I'd like to return to the subject of the opinion paper. Prof Savanije will be aware that the PB framework also includes a planetary boundary on *"land system change"*, the control variable of which is the *"area of forested land as percent of original forest cover"* (Steffen et al. 2015). This is motivated, inter alia, by the fact that *"tropical forests have substantial feedbacks to climate through changes in evapotranspiration"* (Steffen et al. 2015). I guess this is what Prof Savanije had in mind. While I have serious doubts about that planetary boundary, too (see also Brook et al. 2013), I'd like to reiterate that I explicitely and deliberately limited the opinion paper to the issue of freshwater use. I did this *exactly* because the conceivable large scale feedbacks inflicted by consumptive freshwater use might be quite different from those caused by land system change, both in terms of mechanisms and intensity, and are certainly *much* less explored as e.g. the Amazonian vegetation-atmosphere feedback. Still, the planetary boundary literature (Rockström et al. 2009; Steffen et al. 2015) is trying to use vegetation-atmosphere feedbacks in order to justify the freshwater boundary. At this point, I would like to refer Prof Savanije to p. 4, ll. 20-29, of the opinion paper: in that paragraph, I tried to argue that I do not consider references to vegetation-atmosphere feedbacks (e.g. Oyama and Nobre, 2003) as sufficient to justify a planetary freshwater boundary. So while I'd prefer to disagree that I "missed an important feedback mechanism" (as Prof Savanije put it), I very much agree that this point deserves further



clarification, and that a reference to studies such as Van der Ent et al. (2010) would be helpful to illustrate the possibility of large scale feedbacks caused by freshwater consumption. I will try to consider that in a revised version of the manuscript.

We could extend this discussion much further, but maybe not in this specific forum. Because what appears clear to me is that, **yes**, there are mechanisms through which basin-scale water management might affect basins downwind the atmospheric circulation. The linkages and feedbacks are incredibly complex and fascinating, and beyond any doubt worth being explored. Today, however, we do not understand these relationships at a level that warrants any meaningful guidance to water management. Fundamental research is needed to better understand the system. The concept of a planetary freshwater boundary will not help us to address that challenge.

Again, I want to thank Prof Savanije for his efforts. Addressing the above issues - briefly, but explicitely - in a revised manuscript might in fact help to avoid misunderstandings as to a "missing feedback", and thus strengthen the message of the manuscript.

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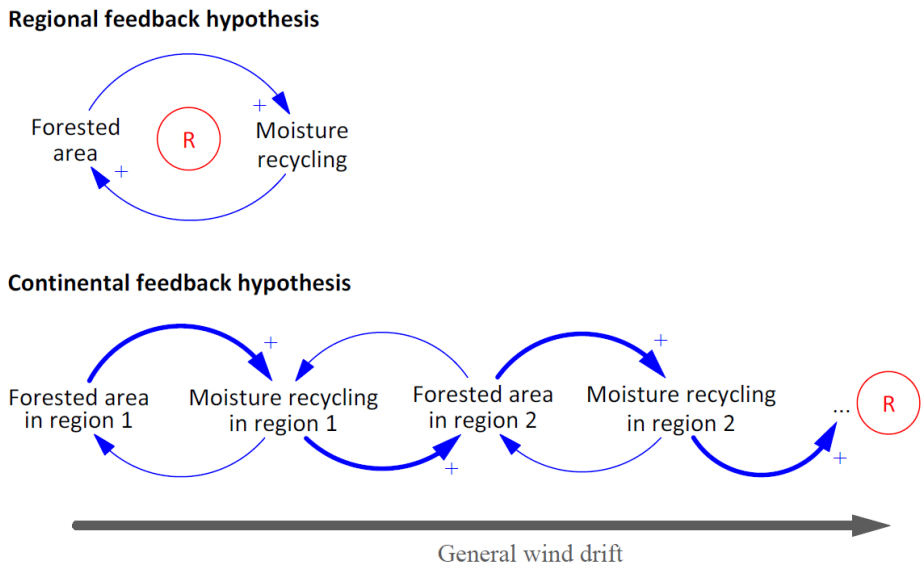


**Fig. 1.** Simplified illustration of positive (R for reinforcing) feedbacks between forested area and moisture recycling; the "+" signs represent interactions of type "the more...the more..."