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Interactive Comment

Interactive comment on "Does the Budyko curve reflect a maximum power state of hydrological systems? A backward analysis" *by* M. Westhoff et al.

M. Westhoff et al.

martijn.westhoff@ulg.ac.be

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We would like to thank Referee 3 for his/her comments and feedback on the paper.

Although the referee finds this paper interesting, he/she has argues that it is rather a technical note than a research paper. We do not agree with this point. Derivation of the Budyko curve from an organizing principle is much more than a technical issue. It deals with a very fundamental issue, namely whether terrestrial systems operate according to thermodynamic optimality. And although we do this in a backwards analysis, where the optimality principle is used as a constraint, the fact that even a relative simple model forced with simplified precipitation and potential evaporation dynamics compares reasonably well with observations, hints that terrestrial systems indeed operate according to thermodynamic optimality.

Other comments of the referee focus on the used assumptions. The first he/she mentions is the assumption that evaporation is at its maximum when the soil is saturated, meaning that the chemical potential is zero. We believe that this is a very reasonable assumption, since the reason for water limitation of actual evaporation is that roots cannot extract water against the strong capillary forces. As there is no water limitation in case of absent capillary forces, actual evaporation can at best be energy limited, which is expressed by assuming actual evaporation being equal to potential evaporation when the soil chemical potential is zero. Note, that this assumption is also used in many other models such as the HBV (Lindström et al., 1997), SUPERFLEX model framework (Kavetski and Fenicia 2011) or the GR4J model (Perrin et al., 2003).

In contrast, we do agree to investigate the assumption of h being a linear function of G_r (although we believe this is a reasonable assumption, since runoff is driven by gravity). For this reply we performed a first sensitivity test, in which h is assumed to be a quadratic function of G_r. For this test, we derived the Budyko curve for a dry spell of six months. As can be seen in Fig 1 of this reply, the differences with the original formulation of a linear relation between h and G_r are minor. In the revised version of our manuscript, we will test some more relations.

Considering Eq. 11, we do agree that this is a somewhat arbitrary function: but this is the very essence of a backward analysis. We chose this function since it satisfies the constraints $P_e(k_e) > 0$ for $k_e \in (0, +\infty)$ and $\partial P_e / \partial k_e = 0$ at $k_e = k_e^*$. We also tested the function $P_e(k_e) = P_0 \exp -((k_e - a)/k_0)^2$, but this led to two values of k_e^*, which was reason to use the formulation of Eq. 11.

We introduced a reference power and conductance in the formula to get the correct units. In all calculations, we have set them to unity.

Concerning the last point, it is indeed a given that when applying Eq. 9, we end up at the Budyko curve. This is also inherent to the backwards analysis we made, which forms the basis of finding relations between h and G_e and between h and G_r.

The gradient $G_e(h^*)$ is the gradient for evaporation corresponding to the relative wetness that lead to a point at the Budyko curve (under constant forcing!). The more general term $G_e(h)$ is introduced because we aimed to build a forward model to test sensitivities to dynamics in boundary conditions. When introducing these dynamics, we first derived the gradients assuming a Budyko curve that follows the asymptotes closely (Eq.9, with $n = 20$). We will better explain this in the revised manuscript (see also our reply to Referee 1).

On behalf of all authors,

Martijn Westhoff

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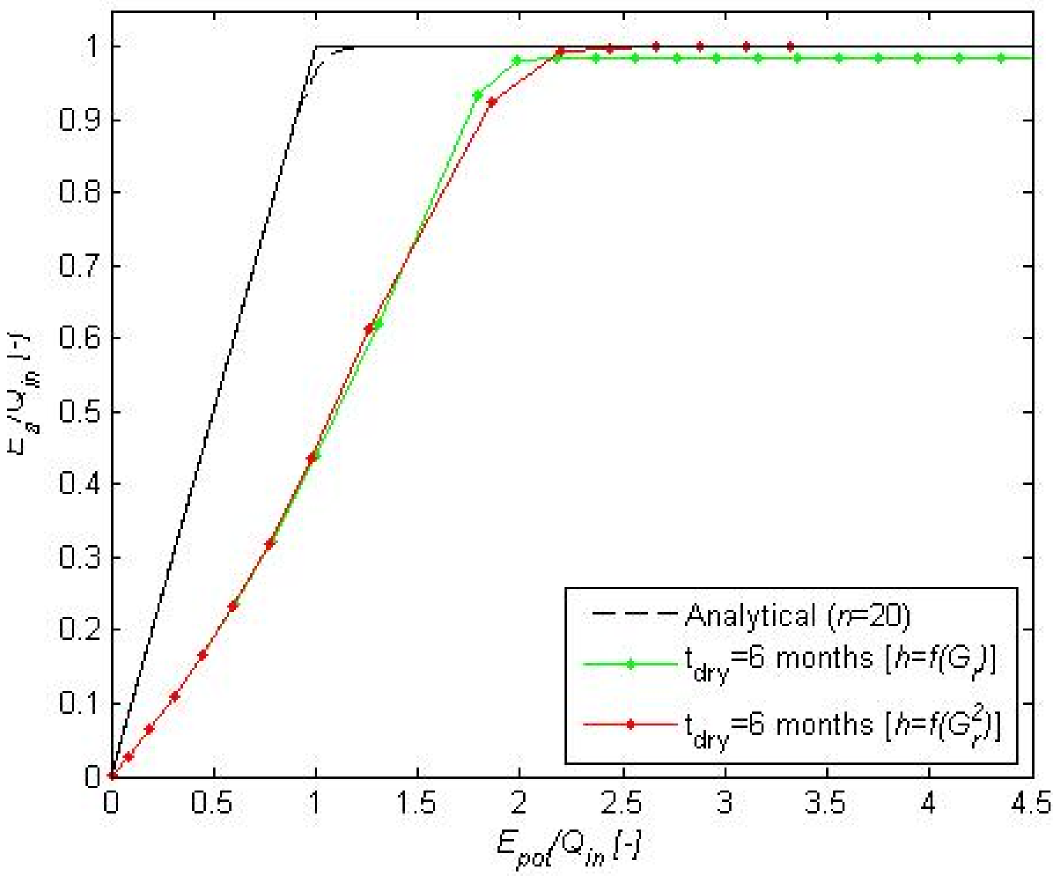

Fig. 1. Sensitivity of h being a quadratic function of Gr vs. h being a linear function of Gr