Hydrol. Earth Syst. Sci. Discuss., 11, C3596–C3601, 2014
www.hydrol-earth-syst-sci-discuss.net/11/C3596/2014/

Hydrology and Earth System Sciences
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Discussions

Interactive comment on "The Budyko and complementary relationships in an idealized model of large-scale land–atmosphere coupling" *by* B. R. Lintner et al.

Anonymous Referee #2

Received and published: 3 September 2014

This work deals with a simplified atmospheric circulation model with analytic expressions under prescribed radiation, moisture advection and tropospheric temperature profiles. The model, which was published by the same authors in 2013, resolves the highly interesting (and scientific challenging) soil moisture – evaporation – precipitation relationship. The focus of this work is to show that the model resolves the complementary relationship (CR, Bouchet (1963)) and to derive analytic expressions for it. The parameter sensitivity is studied and the feedback strength is varied. Further relevant scenarios such as global warming or large scale irrigation are being studied. These analyses (apart from the irrigation scenario) demonstrate the robustness of the em-

ployed model.

Generally, I am much in favor for efforts to reduce complexity to key aspects of land-atmospheric interaction. Such toy models are very useful for the further understanding of how the land-atmosphere interaction actually works and how to represent the most important parts.

The paper is well written and structured and I enjoyed reading sections 1-2 and 4-6. Section 3 was more difficult to follow. The manuscript is a significant contribution to HESS. More detailed critical remarks and suggestions are found below.

Detailed comments

Expression for Budyko relationship

In the abstract the authors claim to derive the Budyko relationship from an idealized prototype for Large-Scale Land–Atmosphere Coupling.

To my understanding, please correct me if I am wrong, the form of the Budyko curve is already determined by prescribing runoff as function of soil moisture as done on P9442L9: $Q = Pw^\eta = P\frac{E}{Ep}^\eta$. Hence, although precipitation P and potential evaporation E_p are model outcomes, they do not change the form of the Budyko curve (Fig.8), because E seems to be fixed by the prescribed runoff power law. Thus only changes in the runoff function change the form of the Budyko curve (Fig. 3). Hence, as the model is set up, one might conclude (as the authors do) that land-surface interaction does not change the form of the Budyko curve.

While this may be true for scenarios where one can assume a steady function for runoff without changes in the storage discharge relation and without vegetation adaptation, it is certainly not true for changes in the frequency and intensity of precipitation (Milly, 1994; Porporato et al., 2004; Donohue et al., 2012).

Given the model setup and especially Section 3.2, it seems to me that the Budyko relationship is prescribed, rather then derived. Please comment on why the Budyko relationship is thought to be derived from the prototype.

As a side note, it would be quite interesting to see, if changes in the parameterization of the runoff power law (which was done for Figure 3) would effect the CR?

Decline of E at large soil moisture The authors report on the behavior that E is declining at higher soil moisture values (P9444L3ff, Fig. 1 and Fig 2). Could it be that this behavior is due to the case that under high soil moisture conditions we typically find humid conditions which are energy limited? Hence $E \leq E_p$ for any case. Such a behavior can simply be demonstrated with the Budyko water-energy framework (using Budyko's curve or Eq. 15) e.g. forced with $P = 1$ and $E_p = 0...10$ and soil moisture $w = E/E_p$ this can be plotted as done in Fig.1a. At high soil moisture, E must converge to E_p, and will decline towards $E_p(w)$.

Model configuration and replication of results The authors should provide all details, necessary to replicate the results, possibly in an appendix or supplement. This is not only required for scientific reasons, but also for intended use case of the model as diagnostic tool of more complex climate models. I could not really follow the configurations of the intervention experiments and the impact experiments. It was not always clear which variables are prescribed and which respond. Actually, a sketch of the prototype model would have been very helpful in understanding the model and how processes are linked to each other. I can however understand that the author want to direct any questions to the first publication of the model prototype.

Prototype transect The authors should explain what they mean with prototype transect, e.g. used P9446L19-20. I.e. what is the spatial resolution of the model/prototype

and how are different moisture states realized.

Large scale irrigation setup Although the scenario is of great interest, especially when focusing on land-atmosphere interaction, the outcome is not what I expected. What I would expect is that irrigation increases E and thus also P. Instead Fig. 9 shows no relevant change in E and a consistent decrease of P, probably by the 2 mm/d of added irrigation. As I can not fully understand the configuration and results I ask for a more detailed explanation. Possibly a water or energy budget at some value of w would help to understand what is going on.

Minor comments:

Normalized form of the slope of the saturation vapor pressure curve γ

Please provide an inline equation of γ along with the explanations on page 9442.

Derivation of analytic complementary relationship I do not fully understand the function $f(T)$ in equations 11-13. Please provide a full form in the appendix.

Statement about temperature dependence of (Priestley and Taylor, 1972) on P9446L12ff The Priestley-Taylor equation has a distinct temperature dependence through the slope of the saturation vapor pressure curve. With that I do not understand the sentence on P9446L12ff.

P9449L5 Typo section **5**

P9449L27ff the description of the experiment (ii) is not clear to me

P9450 the first two intervention experiments are hardly discussed. What does it mean for the feedback and which variables are altered, e.g. when E/E_p is kept fixed?

P9459L27ff unclear explanation, please explain

Table 1: there is a typo for the Priestl**e**y-Taylor coefficient

Axis labeling two panel figures is hardly readable, please increase font size

Fig 2 axis labels are not explained and not consistent with text

Fig.4 unclear unit of y-axis

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Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 11, 9435, 2014.