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

B. R. Lintner et al.

lintner@envsci.rutgers.edu

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We thank Reviewer #2 for a thought-provoking review. We also appreciate the encouragement and support in Reviewer #2's opening summary of our manuscript.

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 = Pwη = P E η. Hence, although precipitation P and potential

evaporation Ep 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 we noted above, Reviewer #1 had similar questions regarding the way in which we either framed our analysis of the Budyko curve or interpreted results.

âĂć 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 $\leq$ Ep 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 Ep = 0...10 and soil moisture w = E/Ep this can be plotted as done in Fig.1a. At high soil moisture, E must converge to Ep, and will decline towards Ep(w).

–>We agree with Reviewer #2 that this behavior is consistent with energy limitation under humid conditions, and we thank Reviewer #2 for pointing out the connection of the Budyko framework. We have added a brief discussion of this at the end of Section 3b.

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 of the model as diagnostic tool of more complex climate models. I could not really follow the con- figurations 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.

–>Rather than explicitly add an appendix or supplement, we have opted to incorporate further clarifying language throughout the text where appropriate. In our view, given the equations we have provided in the text, the table of baseline parameter specifications (Table 1), as well as the values tabulated in the original set-up discussed in Lintner et al. (2013), it should be possible for one to replicate our results.

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 C3598 and how are different moisture states realized.

–>We apologize for not making our usage of the term “prototype transect” explicit. We have thus added the following text (at the end of section 1). Here we are interested in examining the behavior across a range of hydroclimatic states; in what follows, we use the term “prototype transect” to refer to this range. This may be viewed as representing either a spatial sampling of states across a climatological gradient in soil moisture at a fixed point in time or a temporal sampling (as under the seasonal evolution) at a fixed point in space.

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 cannot 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.

–>We believe the incomplete understanding here may stem from the depiction of the quantities in Fig. 9 as functions of soil moisture. We have thus decided to include an additional panel in Fig. 9, depicting Ep, E, and P as functions of horizontal (drying) moisture advection (see Figure 9a). What is evident in this view is that E and P do increase with inclusion of irrigation, consistent with Reviewer 2’s expectation. (We note that we had stated this in words, but this is clearly a case where a figure is far more illustrative!) It is when we plot the results with respect to soil moisture that the “expected” relationship does not appear to hold. In fact, that was our motivation for showing the soil moisture relative values in the first place.

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.

–>The inline equation γ=(dq*)/dT, where q* denotes saturation specific humidity, is now shown inline upon first usage of γ in Section 2.

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.

–>We have defined this function in-line in the text. The point in expression equation (13) as we have done is to emphasize a part that looks like Priestley-Taylor and a “correction” factor that depends explicitly on precipitation and with a temperature dependence inherent in f(T). Since we prescribe T itself, this is just a constant over the transect. We hope this motivation is clear!

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.

–>We were somewhat careless with the description of equation (13). Please see the revised discussion.

P9449L5 Typo section 5

–>Thanks for the catchâĂŤcorrected!

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

–>We have included some additional text to clarify this experiment.

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/Ep is kept fixed? P9459L27ff unclear explanation, please explain

–>As above, we have included additional text to clarify these experiments.

Table 1: there is a typo for the Priestley-Taylor coefficient

–>Thanks for catching the typo-correct!

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

–>Done

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

–>We have added the following to the Fig. 2 caption: The values along the abscissa, EMI, correspond to the ratio of actual to pan evaporation in Kahler and Brutsaert (2006) and are identical to soil moisture in the prototype.

Fig.4 unclear unit of y-axis

–>Corrected.

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