

Interactive comment on “The Budyko and complementary relationships in an idealized model of large-scale land–atmosphere coupling”

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Received and published: 19 November 2014

Reviewer #1 We thank Reviewer #1 for the careful and thorough reading of our manuscript, especially with respect to clarifying language and methodological details.

P9440: did Morton (1983) provide the justification for the complementary relationship over long time scales? I thought the challenge is show why the relationship holds on daily time scale.

→We have revised the language here to eliminate the line in question.

P9443: It is not clear how the relationships shown in Figure 1a were obtained and I
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assume they are from a model? In that case, it would be helpful to provide a brief description of the model.

→The model used to produce Figure 1 is just the prototype outlined in Section 2. However, given Reviewer #1's comment, we have added some text for further clarity.

P9444: If the good correspondence may be coincidental, what these results mean in terms of the prototype?

→We have clarified and added to the discussion: the text now reads: The prototype complementary relationship shows a qualitative, and arguably quantitative, correspondence with both observational datasets. Of course, we should point out that the prototype was not explicitly tuned to represent the hydroclimate of these locations, and as such, any quantitative correspondence may be coincidental. Moreover, the scatter inherent in the observations would permit a range of plausible complementary relationships.

“A slight decrease in E is observed for $W > 0.7$ ”. I am not sure what the authors are referring to here? Please explain.

→We refer here to the slight downward bend in the gray curve in Figure 1a. We have added a parenthetical note to this effect following this sentence.

“We also note that at low soil moisture values, precipitation essentially mimics the E response..”. I find this statement confusing. I thought under low soil moisture values, E would mimic precipitation. I can't understand why this would explain a complementary relationship between precipitation and potential evaporation.

→We simply intended to point out that because E must balance P at low soil moisture, and E is complementary to Ep, then P is complementary to Ep. Given that this may be obvious, we have decided to remove the sentence in question.

P9445: “the prototype's complementary relationship”, is this different from Bouchet's complementary relationship?

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→ The language was meant to convey the complementary relationship as it occurs in our prototype, but we are using complementary relationship in the sense of Bouchet. We have revised the language to (hopefully) clarify.

P9447: what is η ? What is α ? I find the description of the Budyko curve is confusing. The authors frequently refer to the prototype and it would be helpful if this can be avoided.

→ The parameters used are summarized in Table 1: α is the Priestley-Taylor coefficient while η is the power law scaling exponent for runoff dependence on soil moisture. However, we should apologize for an error in this section in which we used $\alpha = 4$ instead of $\eta=4$.

What is the implied slope of Ep vs. E ? Is this the line shown in Figure 1b? What is the significance of the slope?

→ Reviewer #1 is correct about the line in 1b representing the slope of Ep vs. E . The significance here is that the value of the slope represents a convenient measure for the change in the complementary relationship.

P9449: “In contrast to the complementary relationship, the Budyko curve is extremely robust, with no apparent change in the shape for these variations”. The Budyko curve (Budyko, 1974) has no parameter and it is simply a function of the dryness index, but other similar equations can vary depending on the model parameter. The authors seem to suggest that the complementary relationship is not robust. Any evidences to support this claim?

→ Both Reviewers have rightfully identified some deficiencies in our discussion of the Budyko curve. As far as Reviewer 1's point, we used the term robust to describe the Budyko curve when in fact we meant insensitive to parameter change, following the reasoning noted by the reviewer. We have altered the text of this part to reflect a more proper characterization of the nature of the Budyko curve. (We still think it's important

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to point this out, which is why we haven't completely removed the discussion.)

P9450: "Rather than present the complementary relationship..., we instead show the surface temperature and specific humidity profile as functions of soil moisture". Does this mean the surface temperature vs soil moisture relationship can be used to represent the complementary relationship? I find it difficult to follow the discussion. What is the fixed E_p case?

→ In these experiments, by prescribing either the evaporative efficiency β or the potential evapotranspiration E_p , we effectively disable the complementary relationship. That said, we can still compare the behavior of surface temperature and specific humidity in the baseline and intervention experiments.

"This in turn feeds back onto precipitation... with increase water vapour and connective cloudiness". Is this result of the model (i.e. the prototype)? Or this is just a general statement?

→ This behavior is inherent in the physics of the prototype, which we expect should be generally representative of the leading-order large-scale thermodynamic response (especially in the tropics) to warming. Of course, some important aspects are not captured by the prototype, such as changes to convective inhibition, which may have a strong impact on the triggering/frequency of convection.

P9542: Why would E increase under warming at low soil moisture and decrease for soil moisture above 0.5? What are the mechanisms for such changes in E ?

→ At low soil moisture, the vertically-averaged atmospheric moisture balance is between precipitation and evapotranspiration. At higher soil moisture the balance involves a progressively larger moisture convergence term.

P9454: The authors stated that they derived analytic expressions for the Budyko and complementary relationships based on an idealised prototype. Do the authors mean that they have derived Equation (11) and Equation (15)?

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→Upon reflection, we agree with Reviewer #1 (and Reviewer #2)'s comment, namely that we do not "derive" the Budyko relationship, given that Budyko is inherent from the way runoff and evapotranspiration are formulated in our prototype. We have hopefully adjusted the language to the satisfaction of both Reviewers.

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

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