Interactive comment on "New interpretation of the role of water balance in an extended Budyko hypothesis in arid regions" by C. Du et al.

C. Du, F. Sun, J. Yu, X. Liu, and Y. Chen
sunfb@igsnrr.ac.cn, yujj@igsnrr.ac.cn

Dear Referee #1,

Thank you very much for your comments and constructive suggestions in order to improve our manuscript. The point by point response to each of the comments and suggestions is as follows.

Response to the major comments

"*Section 2.3: Equation (9) of the abcd model is a Budyko equation. Wang and Tang (2014) derived a one-parameter Budyko equation base on the generalized proportionality hypothesis originated from the SCS method. This Budyko equation has the same functional form of abcd model for monthly water balance. In abcd model, P+S0 is partitioned into E+S1 and Q. S0 is initial storage for a month; S1 is the ending storage of the month. E+S1 has an upper bound b; but Q has no upper bound. Equation (9) is for (E+S1)/(P+S0) versus b/(P+S0), i.e., a Budyko equation at the monthly scale.*

For mean annual water balance, P is partitioned into E and Q, where E has an upper bound of (E0) but Q has no upper bound. Budyko equation is for E/P versus Ep/P. When S0=0 and S1=0, b becomes Ep and Equation (9) becomes Budyko equation for mean annual water balance. Therefore, the original Budyko equation for mean annual water balance is a special case of Equation (9) for monthly water balance. The meaning of the parameter for mean annual water balance is explained in Wang and Tang (2014)."

Thank you.

We agree that Equation (9) is equivalent to Budyko type equation as well demonstrated by Wang and Tang (2014). We have modified the relevant part in the text (See Line 7, Page 11022).

The point about defining the equivalent precipitation as the sum of the precipitation and the initial soil water content ($P+S_0$) is interesting and was also used in the abcd model (Thomas 1981). Following up that suggestion and the tradition, we examine the relationship between $(ET+S_1)/(P+S_0)$ VS $b/(P+S_0)$, where b is the maximum of evaporation opportunity in Figure A1. In Figure A1, we plot Region I (the upper sub-basin), Region III (the middle sub-basin), and Region V (also the middle sub-basin) and Region VI (the lower sub-basin). We found that those points for Region III, V and VI can exceed the water limit and the relationship of $(ET+S_1)/(P+S_0)$ VS $b/(P+S_0)$ do not follow the original Budyko hypothesis.

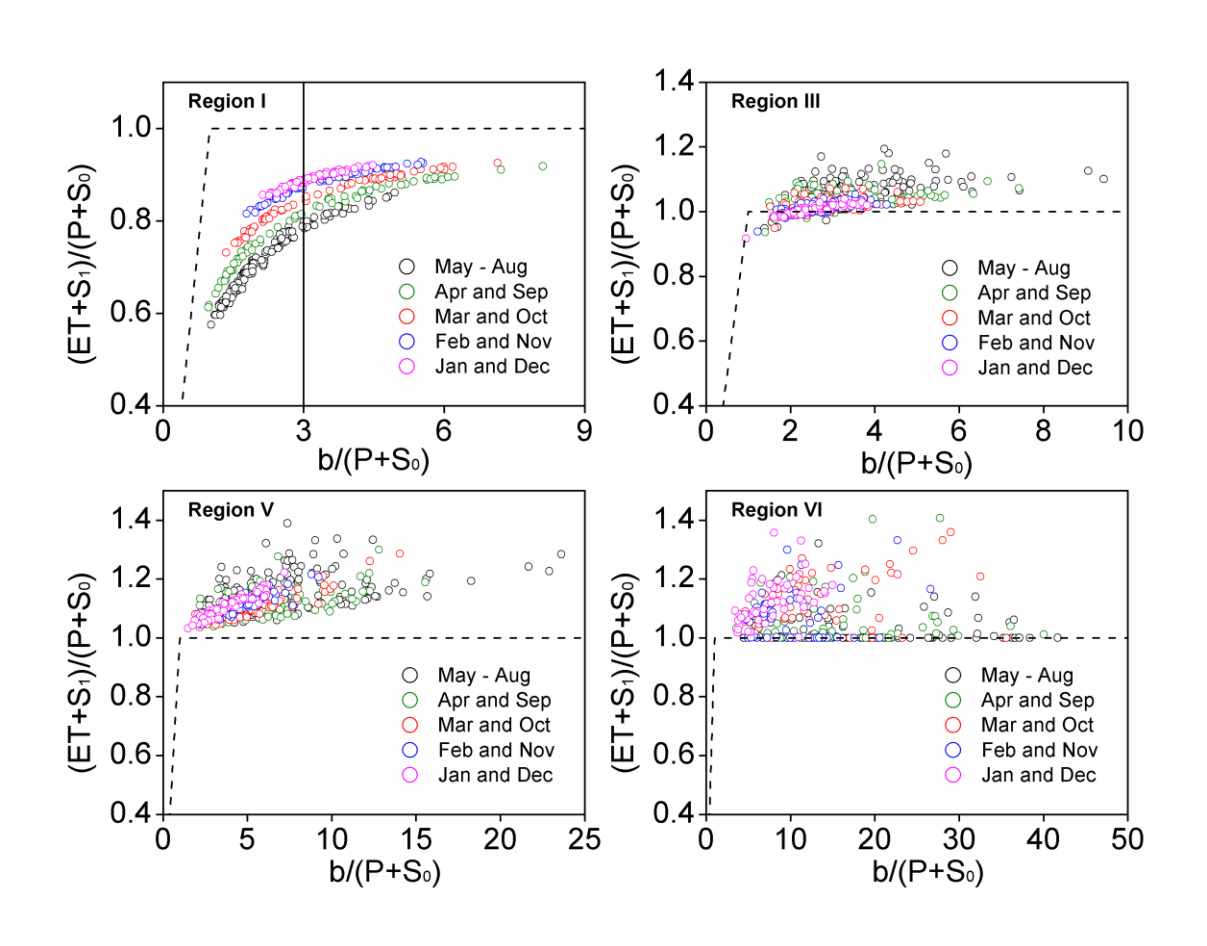

Figure A1. The relationship of $(ET+S_1)/(P+S_0)$ VS $b/(P+S_0)$.

We further examined the relationship of $ET/(P+S_0)$ VS $ET_0/(P+S_0)$ for the same four sub-basins in Figure A2. Compared with Figure 9 in the main text, the points of $ET/(P+S_0)$ VS $ET_0/(P+S_0)$ are scattered and do not fit the Budyko type equations.

Over last several years, theory and case studies about the Budyko hypothesis has well developed worldwide. Our study aims at extending the original Budyko framework to extremely arid conditions, on which discussion is rare. Therefore it becomes crucial to make the Budyko hypothesis applicable and suitable under that extreme condition.

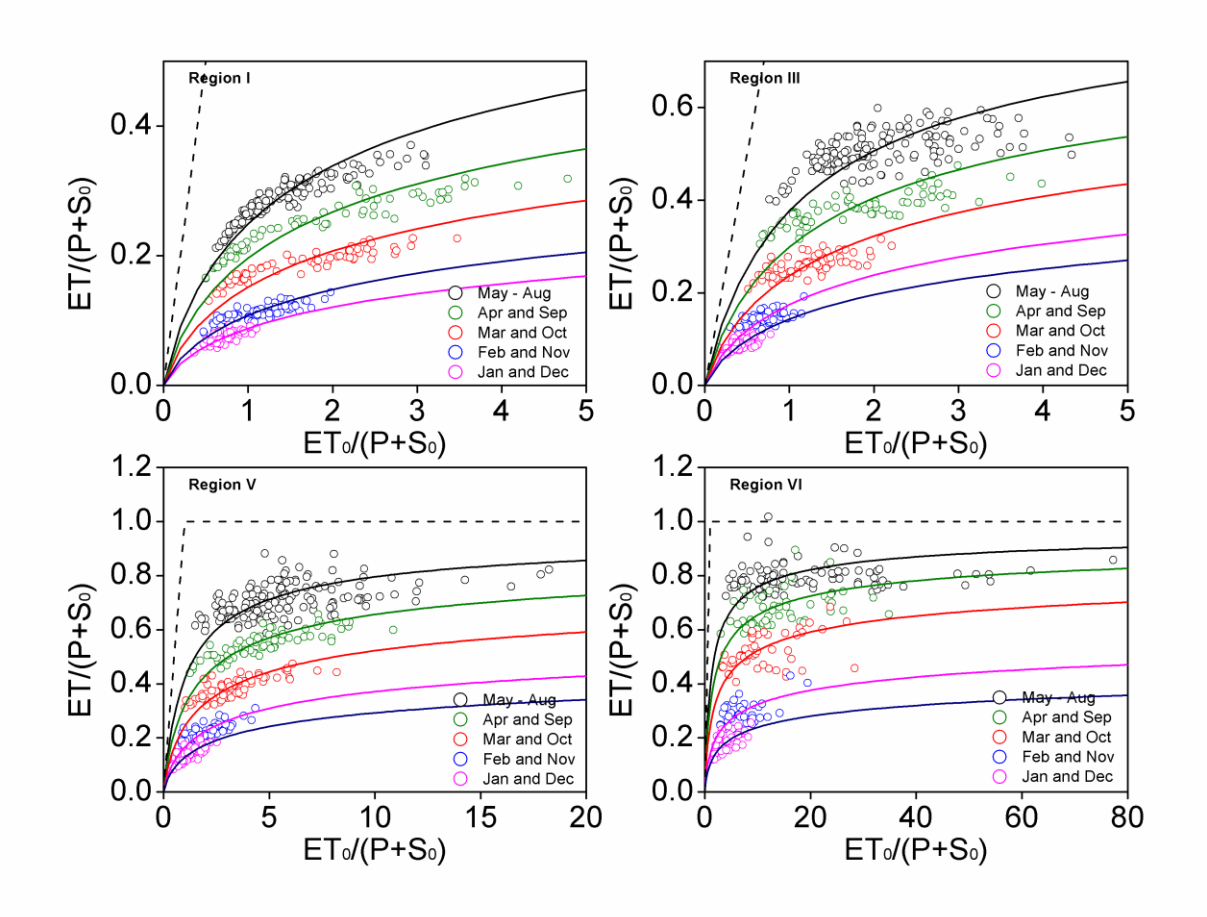

Figure A2. The relationship of $ET/(P+S_0)$ VS $ET_0/(P+S_0)$.

Response to the minor comments

(1) *Lines 18-19 on page 11015: "These equations with parameters" to "These equations with a single parameter"*

Done.

(2) *Line 5 on page 11016: "expand" to "expanded"?*

Done.

(3) *Line 8 on page 11016: "so large-scale human actives" to "large-scale human activities"*

Done.

(4) *Line 23 on page 11016: "and found that"*

Done.

(5) *Line 2 on page 11017: "grant" to "grand"?*

Done.

(6) *Line 11 on page 11017: "flowing" to "flow"?*

Done.

(7) *Line 14-22 on page 11017: The sentence is too long. It is can be break into short sentences.*

Thanks. We now break the sentence into three short sentences.

In this study, our aim is threefold. (1) We first test whether the BH is applicable to the unsteady state condition in extremely arid basins. (2) If not, we further improve the original BH by including observed water balance. (3) We finally extend the applicability of the BH in unclosed basins at annual or monthly time scales.

(8) *Line 11 on page 11018: "interference" to "interferences"*

Done.

(9) *Line 20 on page 11018: I am not convinced by the definition of available water in equation (2), i.e., delta_G is not included for the definition of Pe. See my comment on abcd model.*

We examined this point in Figure 11 to consider the effects of the ΔG in defining the available water. But it does not work well. We suspect that it is to do with that the ΔG does not contribute the evaporation.

(10) *Equation (4) on page 11019: Remove "C" in the equation?*

Thanks. This comment is related to the Comment #12. The constant "C" was derived in the original derivation of Fu (1981) (equation (20)). Over long term mean annual time scale, when the boundary (P→0, ET=0) applies, "C" become zero constant in the original equation and followers of Fu's equation.

However, for much finer timescale like yearly or monthly as investigated here, that boundary (P→0, ET=0) is hard to meet in practice. Therefore in our study, we keep the constant "C" in Fu's equation to have one more freedom. To make a distinction from the widely used form of Fu's equation (without the "C"), here we call it a new Fu-type Budyko equation under unsteady state condition (with the C). As shown in the results we found the new form works better than the original Fu equation (Figure 9). We will test it in our future work over catchments worldwide.

For the physical meaning of the C and its dimensionless form lambda (λ), it is still an open question and requires further investigation. In our current preliminary understanding, over timescales like weekly, or monthly, we expect that it is more to do with rainfall intensity and hydraulic conductivity of soil.

We add a sentence in Line 4 Page 11021 that "We speculate that the λ may be related to rainfall intensity or hydraulic conductivity of soil".

(11) *Line 16 on page 11019: "separating the local precipitation" to "mean annual ET"?*

Yes. "separating the local precipitation" has been replaced by "separating the ET from the local precipitation".

(12) *It will be helpful to explain the meaning of lambda.*

See our response to Comment #10.

(13) *Lines 17-18 on page 11021: Actually, the abcd model was original developed and applied for monthly water balance instead of annual.*

After examining the literature, we agree. We have modified it in line 17 page 11021.

Reference:

Fu, B. P.: On the calculation of the evaporation from land surface, Scientia Atmospherica Sinica, 5, 23–31, 1981 (in Chinese).

Thomas, H. A.: Improved methods for national water assessment, water resources contract: WR15249270, Washington, D.C., Water Rsources Council, 59, 1981.

Wang, D., and Tang, Y.: A one-parameter Budyko model for water balance captures emergent behavior in darwinian hydrologic models, Geophys Res Lett, 41, 4569-4577, doi: 10.1002/2014gl060509, 2014.

Thank you a lot.