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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Reinterpreting the Budyko Framework" *by* Nathan G. F. Reaver et al.

Anonymous Referee #2

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This paper presents interesting tests and perspectives on the Budyko framework. It first argues that there is no theoretical or empirical basis for typical key assumptions in the use of the framework (i.e (i) catchments follow parametric Budyko curves under aridity change, and (ii) the catchment-specific parameter (i.e. n or w) is determined by catchment biophysical properties. Subsequently, the paper aims to test these assumptions using outcomes of the Porporato 2004 model, and empirical data.

While the paper addresses two very relevant aspects of the Budyko framework, there seem to be several conceptual limitations that make the results only weakly support the main inferences of the paper, because:

* The approach using the models is that: "We tested the catchment trajectory conjecture by varying the model climatic parameters while holding the landscape parameter constant. If the resulting trajectories are not Budyko curves, the conjecture should be

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rejected." This approach assumes that the only relevant climate variable is aridity, but in reality as earlier work has shown (and as the model shows) other climate variables (such as seasonal cycles and P intermittency) also strongly controls water balances. Thus, the observation that the model diverges from the Budyko curves only shows that climate also matters (as is already known) and does not show that catchments do not follow the Budyko trajectory conjecture.

* The approach using the data: It is stated that "this prediction can be tested by comparing actual Budyko space trajectories of reference catchments computed from empirical observations against the expectation from the catchment trajectory conjecture. If the observed reference catchment trajectories are distinct from the expected Budyko curve trajectories, the conjecture should be rejected.". However, there are many other reasons why the trajectories do not follow the Budyko curves. For example, the water balance may not be closed, measurements may be off, climate variables (other than aridity) may also change (since land-cover is the only variable which is controlled for). Therefore it seems somewhat unfair to attribute any anomaly from the curve to solely the Budyko trajectory being wrong, rather than that is also could be caused by any of the other factors.

* To what extent are the methods sensitive to the use of the Hargreaves potential evaporation over any other PET estimate? In theory it seems that the ambiguity of the PET estimate has similar problems as that of catchment specific parameter in the Budyko framework (e.g. suffering from non-uniqueness and potentially crossing trajectories).

Beside these limitations, the paper nicely contrasts the large number of of Budyko studies that "blindly apply Budyko equations", and emphasizes some shortcomings of the framework that are too often ignored. Once the above issues are addressed (and the detailed comments below) I think this paper could make an excellent contribution to the literature.

Detailed comments

Page 1

L18: “components” or “assumptions”?

Page 2

L3: “rainfall” should be changed into “precipitation” (as it also includes snow). This change is also recommended at other places where rainfall is stated, but precipitation may be more appropriate.

L30: Note that the Gentine et al. (2012) study excluded most US catchments with loads of snow or out of phase precipitation regimes (i.e. Mediterranean). As a consequence, most scatter was removed, resulting in this interpretation.

Page 3

L13: It is stated that “we critically reinterpret two key and interrelated components of the current framework:”. I am unsure these two things can be called “components”. They are rather typical assumptions that people make, but as past authors acknowledge (as referenced by this paper, or as stated above in this review) these assumptions appear largely unfounded, untested, or premature.

L15-17: I appreciate the paper is trying to be gentle towards past research by saying “However, we stress that the aim of this reinterpretation is not to discard the voluminous efforts put forth using current interpretations of the Budyko framework, but rather to recontextualize the conclusions obtained from them”. However, your work suggests that all attributions and sensitivity applications will have substantially wrong numbers. This obviously is important “context” but I’d rather say they also cast doubt on many of the past conclusions.

Page 5:

L14: Schreiber, 1904 was not aware yet of the concept of potential evapotranspiration, so I am unsure it is appropriate to cite this work here.

L18: identical ðÌŚČÌĚ and ðÌŘÿ0 ÌĚÌĚÌĚ seems somewhat inaccurate, as it is about the ratio of the two.

Methods

Page 10

L “(e.g., (“ the second layer of brackets seems redundant

Page 11:

Section 3.1.1: This test seems inappropriate for its cause, because climate chararististics other than aridity are varied.

(Also, see main comment above).

Section 3.1.2: Note that similar types of test have been done in https://onlinelibrary.wiley.com/doi/full/10.1002/hyp.9949 and https://www.nature.com/articles/ncomms11603

L18-20: selecting catchments with stable land-use makes the assumption that all other time-varying factors controlling the catchment’s water balance (besides aridity) are irrelevant, but this is inaccurate as, for example, seasonal cycles of P can strongly vary between years (and strongly influence the precipitation partitioning).

L20: as a consequence, it is hard to agree with “must be attributed to climatic factors and the catchment trajectory conjecture predicts that their expected trajectories through Budyko space must be Budyko curves”. Are the ways to address this critical limitation (given its purpose) to your test?

L28: “ðÌŘÿÌĚ were calculated from the catchment water balance, ðÌŘÿÌĚ = ðÌŚČÌĚ − ðÌŚĎÌĚ. ” is an obvious way to approach the problem, but also known to have issues: https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2020WR027392. What are the potential effects of storage changes (even over 10-y time-scales).

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Page 12: “applying moving-average window sizes ranging in annual steps from 1 year to the full length of record.” How is it justified to use 1-year windows as these clearly can violate the delta S =∼0 assumption?

L25: Why Hargreaves PET, and are there any changes to the results when other PET estimates would be used?

Page 14:

It remains unclear to me what the purpose is of section 3.2.2. (Yes I see WHAT is done, but it seems not really explained WHY this is done).

Results and Discussion

Section 4.1.1.

All these results seem to show that climate variables other than aridity also affect the partitioning of P into Q and E. This seems to be a strange way to test the catchment trajectory conjecture because if the resulting trajectories are not Budyko curves, it just means that climate (other than aridity) also influences the water balances, rather than being a test of the catchment trajectory conjecture. (See main comments).

Section 4.1.2

L6: “their global behaviour”. Can this be made more specific (i.e. does it refer only to the long-term mean water balances (e.g. black markers)?).

Questioning that the prevailing interpretations of Budyko curves suggest that the explicit functional forms represent trajectories through Budyko space for individual catchments undergoing changes in aridity index has also been discussed in https://onlinelibrary.wiley.com/doi/10.1002/hyp.13958 and tested in https://www.nature.com/articles/ncomms11603. This may be worth acknowledging.

Figure 2: is there any way to better visualise what is going on here? One minor change (that will not resolve all issues) may be to make the x-axis on a log-scale. This avoids

that humid catchments are all condensed in a tiny part of the left side of the figure (whereas arid catchments are spread out at the right-hand side).

L4.2.2.

please specify that it is the common interpretation not ALL interpretations in “should cast doubt on the current interpretations of parametric Budyko equations,”

Conclusions

“We suggest that process-based evapotranspiration models be used” Note that this is consistent with earlier works: e.g. https://doi.org/10.1029/94WR00586, https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2005WR004606, etc).

“The general Budyko curve behavior can and should be utilized as a global constraint”. The “should” seems a bit odd as there will be many instances in which there will be better/more data available than the Budyko curve to constrain models.

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