Response to open review comments by Dr. Wouter Berghuijs

Thanks for taking the time to review our paper. Here is our detailed response to your comments.

- It is stated that Budyko has been verified "over thousands of natural watersheds around the globe". However, the studies that you cite are not necessarily at the watershed scale (e.g. Williams is a FLUXNET based study, using plot scales), nor do I expect that all the thousands of watersheds in the other studies can be classified as "natural". In addition, what does "verified" really mean here? (Note hereby that e.g. many of Williams points fall outside the energy and water limits; Sivapalan does not present any Budyko curve in its study (only related concepts)).

Response: We have modified the sentence. Changed "thousands" to "numerous". Removed Williams et al., 2012; Sivapalan et al., 2011. Added Sankarasubramanian and Vogel (2003), Li et al., 2013.

- It is stated that there ". . .is a critical need to enable a complete understanding of global hydroclimate during the Anthropocene. The Budyko framework provides an ideal approach for such inquiry. . ." Prior to this statement, many aspects of change are listed, including flood changes. Listing this example, and stating you want a "complete" understanding of hydroclimatic change suggests to me that it should include changes in floods as well. What is your logical basis for using Budyko for understanding flood changes since its original use and assumptions have very little to do with hydrology at the short time-scales over which many floods are produced?

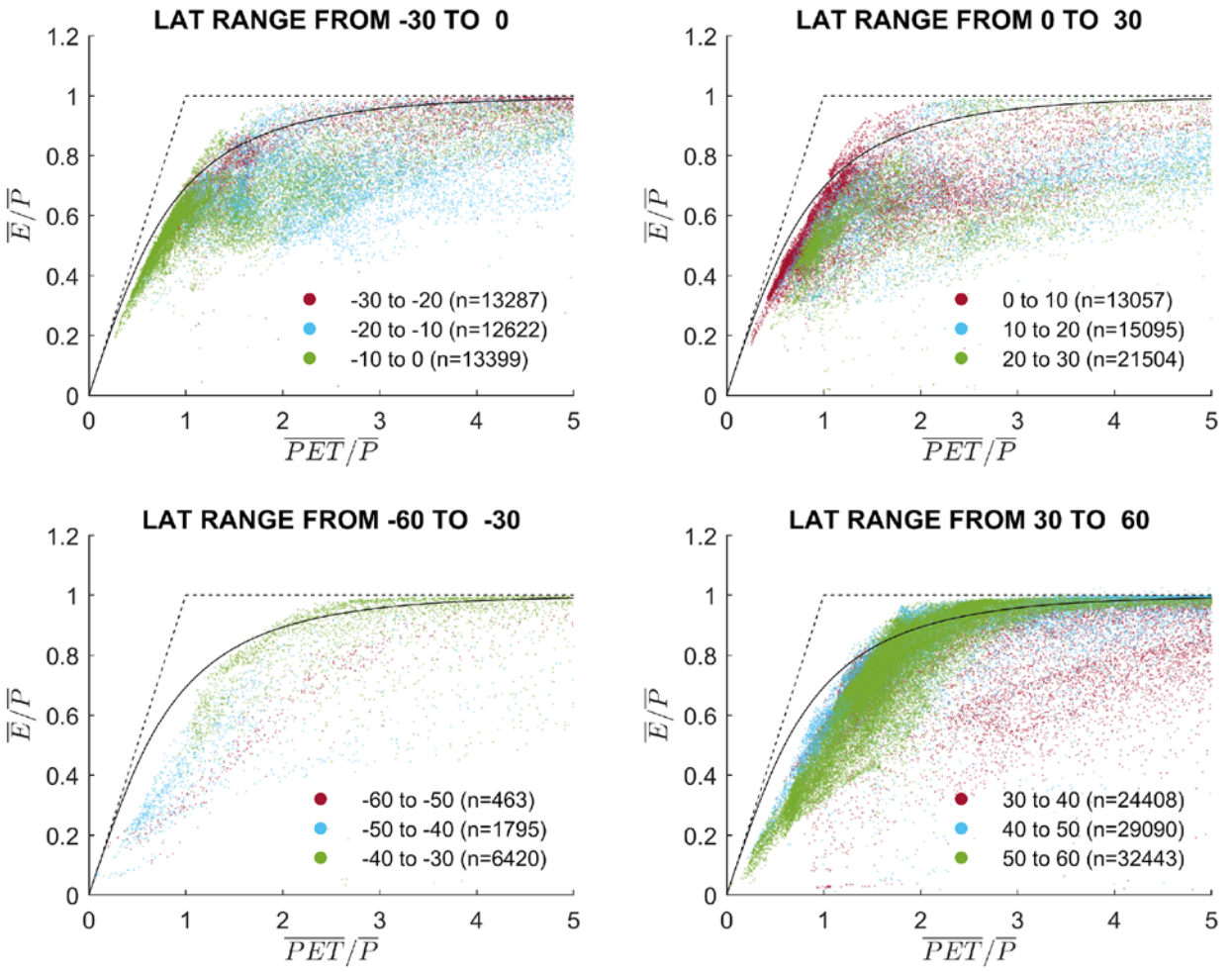
Response: In this context, we mention several hydroclimatological processes that have changed over time due to anthropogenic influences. Flood is one of them. Our argument from this paper is that Budyko's framework can be extended to even shorter time scales. For instance, Figure 3 presents the framework for infiltration, which is an event scale hydrological process. Flooding could be considered as the land-surface response in excess of infiltration. Thus, the idea is to propose possible novel extensions of the Budyko Framework so that low dimensional nature of the process and the associated drivers could be identified.

- It is stated that "Studies have also focused on the impact of land cover and climate on long-term water yield using global data (Zhou et al., 2015)". However, this study is mathematically flawed; see https://www.nature.com/articles/ncomms14795. This makes me question if this study is a good example to cite. . .

Response: We agree with this suggestion. We have removed this reference and added Li et al., (2013) and Wang and Tang (2014).

- In the section “Long term water balance” (line 106 and onwards) the ability of the original Budyko curve is tested in explaining global water balance variability. However, the ET data to which it is compared is model output. Would it make sense to use something more directly observation-based, to avoid that it remains unclear to what extent scatter around the curve is based on real-world behaviors, and to what extent it arises from inaccuracies of GLDAS? The fact that (almost?) not a single data point with aridity $<\sim 1$ plot above the Budyko curve is hereby interesting since this is not typically observed in other datasets (as far as I am aware).

Response: The reason we did not use observed data in this Figure is because numerous studies have demonstrated the applicability of Budyko’s curves for observed datasets (Sankarasubramanian and Vogel, 2003; Abatzoglu et al., 2017 and others), hence we are not presenting it. Further, presenting the long-term water balance from the GLDAS2 dataset shows the performance of the Budyko curve over various latitudes.To make the latitudinal distribution of fluxes as per the general circulation cells, we have revised Figure 2 with grouped at 10° intervals. The key point from the figure is that there is a lower bound on the evapotranspiration ratio for each aridity index range, which emphasizes the need for other controlling factors such as seasonality of forcings (precipitation and temperature) and soil water holding capacity in influencing the long-term water balance. Further, these low ET ratio happens in the horse latitudes (20-40 N), whereas high ET ratio happens in places with rising circulation cells (0 to 10 N and 50-60N). In the case of the southern hemisphere, organization of circulation cells do not strictly follow latitudinal patterns as the land surface being proximity to the ocean, which makes ET ratio varying substantially from the circulation patterns.



- It is stated that "[. . .] limited/no effort has been undertaken on how this data cloud of long-term water balance cloud is expected to change under potential climate change and how this interplay between moisture and energy is expected to affect the long-term water balance under different type of watersheds (Creed et al., 2014)." However, at the same time, your paper states that Budyko can be straightforwardly used to decompose the effects of climate change vs human influences (e.g. line 90-94), which also implies that you can straightforward use it to predict. . . This seems to be somewhat contradicting?

Response: We have revised this sentence to reflect the points mentioned decomposition methods suggested by Wang and Hejazi (2011), who used the observed data to decompose changes in climate and human influence. The previous sentence with Creed et al., (2014) focuses on changes in water balance under climate change.

- The discussed “Extension of Budyko’s “supply and demand” concept for infiltration” (and other suggested extensions) sounds interesting. However, we need to be aware that plotting variables using demand & supply axes that BOTH have the same term in their denominator partly show strong correlations/patterns because they have spurious self-correlations due to a common denominator [Bensen, 1965; Brett, 2004]. This does not mean we should not use it, I just think the community sometimes forgets about this fact (for example, it’s rarely acknowledged that Budyko itself is partly a spurious self-correlations due to a common denominator).

Response: The strong relationship between the “Actual/Supply” ratio to the “Demand/Supply” ratio is statistically due to the presence of “supply” variable on both axes, but that does not mean that there is no causation. All the extensions presented in the manuscript as well as the original long-term balance preserve mass and energy balance between the “actual”, “supply” and “demand” variables.