-------------------------------------- Responses to RC2 --------------------------------------

Understanding the effects and mechanisms of climate variability and vegetation dynamics on fluvial water balance is helpful for hydrological modeling, forecasting and water management. Several studies assessed the impacts of the mismatch in water and energy in terms of a seasonality index (SI) on hydrological cycle, such as Milly, 1994, Woods, 2003. However, previous studies didn't consider the phase difference between seasonal P and E0. Hence, the authors proposed a new index, named climate seasonality and asynchrony index (SAI). They found that the SAI performs much better than the old SI in Budyko framework. On this account, the authors make an important addition to the literature of hydrological studies. In general, the manuscript is in the scope of HESS and I agree with its scientific objective. Especially, the proposed SAI, and the semi-empirical formula for the spatiotemporal variation of parameter n are valuable for the Budyko framework related hydrological studies. Therefore, I strongly recommend acceptance of this paper in view of its importance and newness in results after minor revisions.

Re: Thank you so much for your recognition to the article. We feel great appreciate for your professional review work on our manuscript. We will modify this paper strictly according to your request.

1. Abstract: The first sentence of the abstract, what's the meaning of "The partitioning of water and energy"?

Re: It means that the partitioning of precipitation between evapotranspiration and streamflow. This sentence has been rephrased as "The partitioning of precipitation into runoff (R) and evapotranspiration (E), governed by the controlling parameter in the Budyko framework (i.e., n parameter in the Choudhury and Yang equation), is critical to assess the water balance at global scale."

2. Abstract: "a climate seasonality and asynchrony index (SAI) were proposed in terms of both phase and amplitude mismatch between P and E0." Who proposed SAI? Please rephrased this sentence.

Re: We are sorry for our unclear statement. This sentence has been rephrased as follow: "To reflect the mismatch between water supply (precipitation, P) and energy (potential evapotranspiration, E_0), **we proposed** a climate seasonality and asynchrony index (SAI) in terms of both phase and amplitude mismatch between P and E_0."

3. Introduction: The authors should provide a nicer literature review, so they can have a clearer description of the novelty of this study. Their current lecture review is not sufficient to refer back to the literature. Berghuijs and Woods 2016 and Abatzoglou and Ficklin, 2018 have also considered climate seasonality into Budyko. The authors should state the differences between their work and existing studies.

Re: As suggested by the reviewer, we have added more references to review the climate seasonality. The SAI proposed in this study is based on the hypothesis that the monthly precipitation and potential evapotranspiration are follow the sine function. Fittingly, Berghuijs and Woods (2016) found that the sine function can fully describe the vast majority of the monthly precipitation and temperature over the globe. But they didn't investigate the climate seasonality, i.e., the mismatch of water and energy. However, this reference is important to support the SAI, we added this reference in the method.

Similar to previous studies (Woods, 2003; Ning et al., 2017; Yang et al., 2012), the climate seasonality used in Abatzoglou and Ficklin (2018) also have not considered the phase mismatch between P and E_0. We have added this reference in revised manuscript. The text states as follow: "Climate seasonality (SI) was identified to reflect the non-uniformity in the intra-annual

distribution of water and energy, which plays a role in the variation of controlling parameter in the Budyko model (Woods, 2003; Ning et al., 2017; Yang et al., 2012; Abatzoglou and Ficklin, 2017). It is noted that distributions of water and energy were reflected not only by differences of seasonal amplitudes of P and E_0 but also by the phase mismatch between P and E_0. In this case, we proposed a climate seasonality and asynchrony index (SAI) to reflect the seasonality and asynchrony of water and energy distribution."

4. Equation (11): The authors decomposed the changes of parameter n as a function of SAI and M. How does this work? Do they used complementary method? or Total differential decomposition? Please give more details. Either way, the authors should explain how they subdivided series into two periods.

Re: The decomposition of n into SAI and M is based on the total differential method, which has been added in the revised manuscript. We subdivided the series into two periods based on the changepoint. We have added more details to explain how we do this in the revised manuscript. The text states as:

"We used Ordered clustering test, Pettitt test method and AMOC method to detect the change points of R. To avoid possible uncertainty results based on the individual method, the assembled change points were confirmed with more than one method. If the results for all the three methods are different, the median change point would be selected (Liu et al., 2017a). Based on the changepoints of R and the changes rates of P_e, E_0, M and SAI before and after change points (Table S3 in the supplement), the contributions of these four factors to R and E were assessed (Figures 8 and 9; Table S3)."

5. Figure 3: the color for the below three subgraphs is difficult to distinguish. I suggest the authors used the larger plots and a discrete color bar with more different colors.

Re: Thank you for your kind suggestion. We have remade these subgraphs (shown as below).
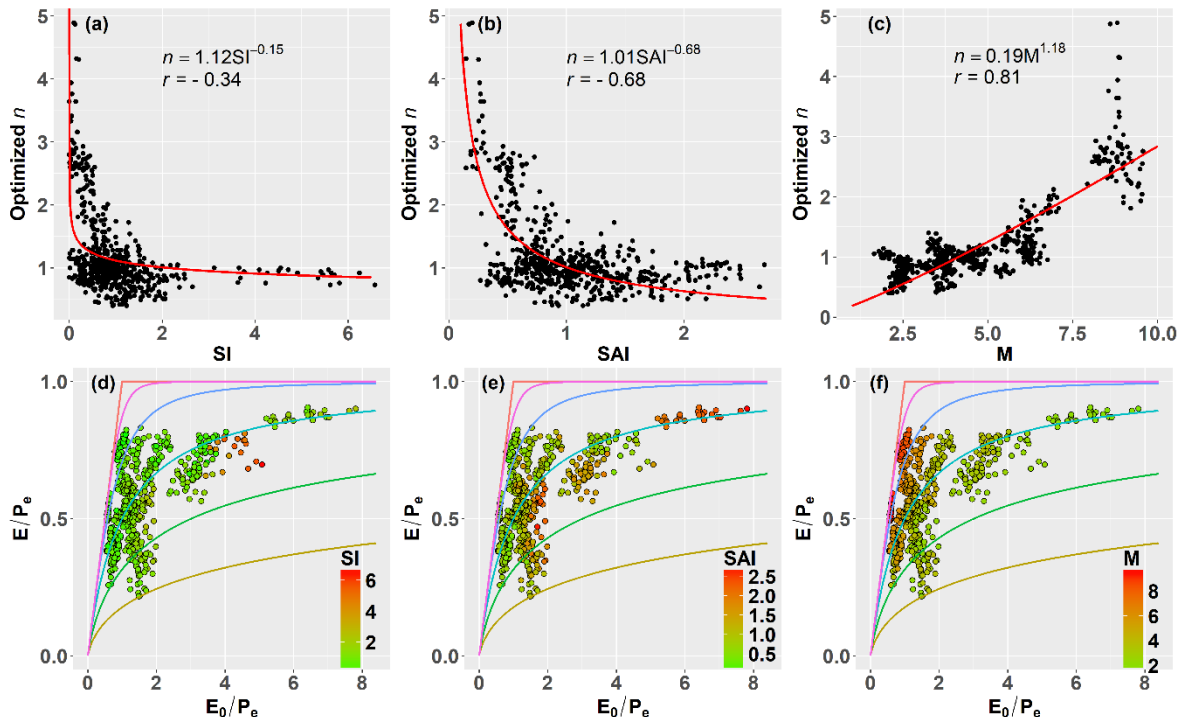
Figure 4. Relationship between optimized n and (a) SI, (b) SAI and (c) M. (d-f) Distribution of evapotranspiration ratio (E/P_e) as a function of the aridity index (E_0/P_e) classified by 26 global large river basins at annual scale. The Budyko curves from the top down are derived from eq. (2b) with $n=\infty$, $n=5$,

n=2, *n*=1, *n*=0.6 and *n*=0.4, respectively. Noted that each point represents one year based on the combined dataset from 26 global large basins.

6. In figure 4 and 6, the author used the R2 and MAE to assess the simulation accuracy. I am curious that why they didn't use the Nash-Sutcliffe efficiency. A high R2 just means a high relationship, rather than a high accuracy.

Re: Thank you for your kind suggestion. The R2 has been added in the Figure 5 and 7.

7. The structure of 4.1 section is difficult to follow. They analysis the Figure 3 and 4 in the first paragraph, then they analyze the Figure 3 again in the next paragraph. Please recombine these sentences.

Re: Thank you for your kind comment. We have recombined and rephrased this section to make it easy to follow. In the 4.1 section, we split the first paragraph into two parts, and then combined the latter part with the third paragraph as the second paragraph. Finally, we rephrased the fourth paragraph.

8. The authors descript the mismatch of water and energy in three scenarios in terms of the SAI and 1-DI. However, does the SAI always belong to these scenarios? How about SAI = 1-DI or SAI = DI-1? Given that the SAI is the main innovation of this study, I suggest the authors give some illustrations for these scenarios of SAI.

Re: We have merge the case of SAI = 1-DI or SAI = DI-1 into the third case, that is (3) SAI $\geq$ |DI − 1|, given that a larger SAI implies more surplus of *P* for the wet season with $P(t) > E_0(t)$.
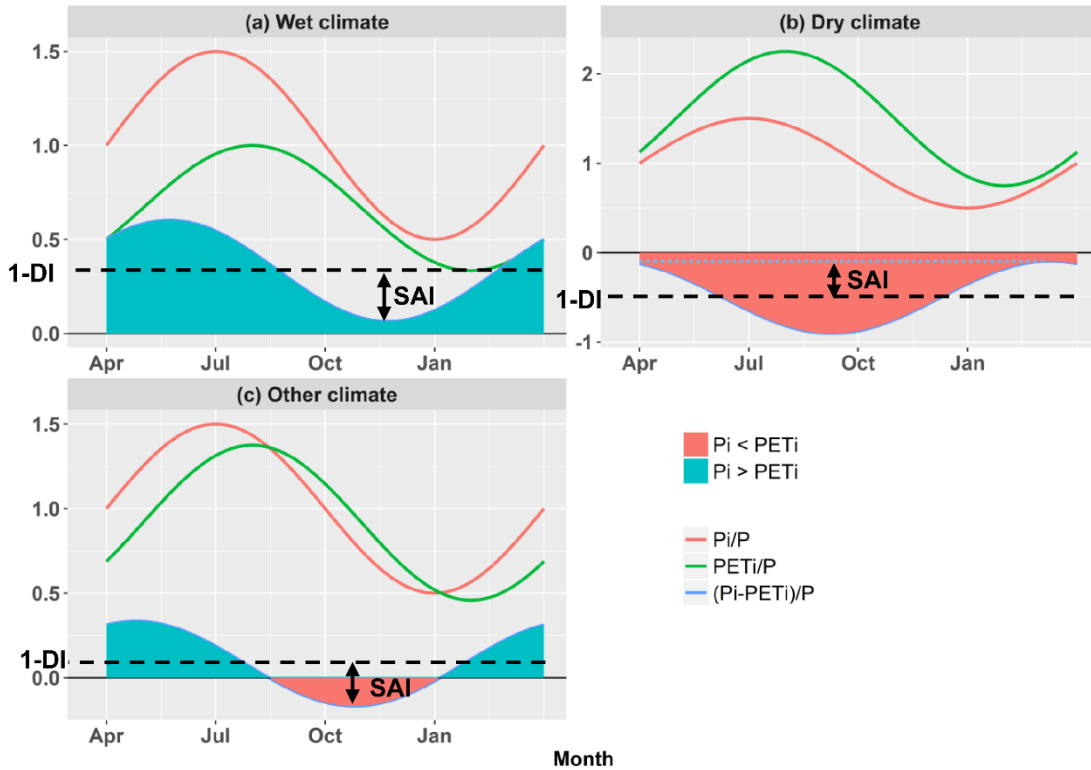
Figure 3. Examples of three scenarios for the mismatch between water and energy in terms of the relationship of SAI to 1-DI. (a) SAI smaller than 1-DI, implying *P* larger than PET in the whole year. (b) SAI smaller than DI-1, implying *P* small than PET in the whole year. (c) SAI smaller than 1-DI, implying a larger SAI means more surplus of *P*. The shaded areas represent the difference between precipitation and potential evapotranspiration, which equal to $(1 − DI) + SAI \sin\left(\frac{2\pi}{\tau}\frac{t}{12} + \varphi\right)$.