

Responses to Comments from Nima Zafarmomen

General Comment: The study is highly commendable for its conceptual paradigm shift. Rather than treating E_P solely as a meteorological input derived from independent equations (like Penman or Priestley-Taylor), the authors introduce the concept of "Budyko E_P ." By inverting the Budyko framework to derive E_P from observed precipitation (P) and runoff (Q), the authors effectively treat E_P as a variable constrained by the catchment's water-energy balance. The development of a conversion function to bridge the gap between meteorological E_P and Budyko E_P is a practical and elegant solution. It significantly improves actual evapotranspiration (E) estimation accuracy (by ~35%) without requiring the complex auxiliary data (soil, vegetation, etc.) typically needed to calibrate the Budyko parameter (n). This makes the method particularly valuable for data-scarce regions.

Response: We sincerely thank Dr. Zafarmomen for the positive evaluation of our work in conceptual and methodological innovations. Our detailed responses to the specific comments are provided below.

Minor comments:

Comment 1. You utilize an 11-year window to assume $\Delta S \approx 0$. While this is standard in Budyko literature, the MOPEX dataset includes catchments where human interventions (e.g., groundwater extraction or reservoir regulation) might impact this assumption. A brief sentence in the Discussion regarding the sensitivity of "Budyko E_P " to non-zero storage changes would add robustness.

Response: Thanks for your comment on the assumption of $\Delta S \approx 0$. We agree with your concern that, in some MOPEX catchments, long-term changes in water storage may not equal zero due to human activities such as groundwater abstraction and reservoir regulation. Following your suggestion, we will add a clarification in the revised Discussion, noting that when $\Delta S \neq 0$, Budyko E_P may exhibit sensitivity to long-term water storage changes, thereby improving the robustness of the methodological description.

Comment 2. The contrast between the MOPEX catchments and the Chinese Loess Plateau (CLP) regarding the "negative conversion relationship" (Fig. 7) is one of the most interesting parts of the paper. I suggest expanding slightly on the physical mechanism here—specifically, how the high aridity and limited water availability in the CLP drive the strong negative correlation between E and meteorological E_P .

Response: Thanks for your attention to the differences revealed in Fig. 7. After establishing the conversion function for the MOPEX catchments, we further examined its generalizability and therefore conducted a supplementary analysis based on CLP catchments. The results indicate that the form and expression of the conversion function are influenced by the complementary relationship for evapotranspiration and its spatial heterogeneity, which is just a preliminary conclusion.

In the CLP catchments, E exhibits a negative correlation with E_{P-Pen} . Under water-limited conditions, E is primarily controlled by water availability. In such cases, a reduction in latent heat flux leads to an enhancement of sensible heat flux, resulting in drier near-surface air and, consequently, increased atmospheric evaporative demand, which is reflected as higher E_{P-Pen} (Brutsaert, 2015; Bouchet, 1963; Han and Tian, 2018). In contrast, no obvious complementary relationship between E and E_{P-Pen} is observed overall across the MOPEX catchments, suggesting that complementary relationship exhibits regional heterogeneity. This warrants further investigation, given the multiple controlling factors of regional evapotranspiration, including solar radiation, atmospheric circulation, catchment surface characteristics, and water supply conditions. Additional discussion on this issue will be included in the revised manuscript.

Comment 3. In Eq. (3) and (5), n is the landscape parameter. It would be beneficial to explicitly state that in the "reference Budyko E_P " approach, the framework essentially reverts to a non-parametric state, thereby shifting the "catchment-specific information" from the parameter n into the adjusted E_P value itself.

Response: We appreciate this insightful and inspiring comment and agree with this view. The reference Budyko E_P contains catchment feature information, and the same is true for the adjustable Budyko E_P . This point will be stated explicitly in the revised manuscript.

Comment 4. The study successfully demonstrates that E_P is not just a climate driver but is intrinsically linked to the catchment's hydrological state. To further strengthen the discussion on how surface characteristics and vegetation dynamics influence these water-energy interactions—which indirectly affect the Budyko E_P you've defined—I strongly recommend considering and citing studies that explore the integration of surface-level observations into hydrological frameworks, such as: Assimilation of sentinel-based leaf area index for modeling surface-ground water interactions in irrigation districts.

Response: We appreciate this important suggestion and fully concur with your viewpoint. E_P is not determined solely by meteorological factors, but is closely related to catchment surface characteristics including vegetation dynamics. As demonstrated in your study (Zafarmomen et al., 2024), incorporating vegetation dynamics into hydrological modeling frameworks helps to characterize surface-groundwater interactions and their regulatory effects on water-energy coupling processes, which indicates that vegetation states can influence potential evapotranspiration from a process-based perspective. The Budyko E_P in this study is grounded in the Budyko water-energy coupling framework and reflects the integrated effects of these factors at the long-term scale. Following your suggestion, relevant literature and discussion will be added to the revised Discussion.

Comment 5. In Section 3.3, you employ a linear form for the conversion function ($E_{P-Budyko} = aE_{P-meteor} + b$). While the scatter plots (Fig. 5) support this, did you test any non-

linear (e.g., power or exponential) forms? Briefly mentioning why the linear form was preferred (likely for simplicity and parsimony) would be helpful.

Response: As you correctly pointed out, the linear form of the conversion function in this study was chosen to satisfy statistical significance while maintaining methodological simplicity. Previous studies have shown that different meteorological E_P estimates often exhibit strong linear relationships (Proutsos et al., 2023; Kim et al., 2023). Because Budyko E_P explicitly reflects the influence of catchment features, its relationship with meteorological E_P warrants further investigation, particularly with respect to the regional variability and nonlinear fitting of this relationship. With E_P expressed by the conversion function, the non-parametric Budyko equation is transformed into a two-parameter (a, b) model, and the parametric Budyko equation is extended to a three-parameter (n, a, b) model. These aspects will be further discussed in the revised manuscript.

Thanks again for the valuable time, suggestions, and comments!

Reference:

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