

Communication

Comment on “Physical Interpretation of the Complementary Relationship for Evapotranspiration” by Sha Zhou and Bofu Yu, Published in Hydrology and Water Resources

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Abstract: The performance of the complementary relationship (CR) evaporation model of Zhou and Yu is tested by routine meteorological data and eddy-covariance (EC) derived measurements of monthly LE values from FLUXNET. Results indicate that globally calibrated single-parameter thermodynamics-based CR versions perform significantly better in predicting EC-derived LE fluxes than their similarly calibrated model, thus challenging their physical interpretation of the processes involved

Keywords: complementary relationship of evaporation; thermodynamics; FLUXNET data

Zhou and Yu [1] present a “physically-based” complementary relationship (CR) model formulation of land evapotranspiration (ET) on an assumed constancy of the Bowen ratio [of sensible (H) and latent heat (LE) fluxes] “regardless of surface moisture changes” at the surface. They list why other existing CR models “face notable practical limitations” including the “inability” of the Priestley-Taylor equation [2] “to adequately quantify wet-surface evaporation”, and the underestimation of the Penman equation [3] because it “neglects energy transfer from the surrounding environment”. They further claim that all these “uncertainties hinder the reliable application of CR for ET estimation in diverse climatic and surface conditions”.

Zhou and Yu then demonstrate “how these uncertainties can be minimized (sic) by accurately estimating” the (apparent potential) ET of a small wet patch, i.e., PET_a , and the ET rate of a wet surface of regional extent, PET_e . (In this comment the same notation is kept for these two variables.) To do so, however they employ surface available energy (Q) and monthly aggregated measured sensible heat fluxes (H) which brings into question the purpose of estimating LE with the help of the CR as it is already obtainable as $Q - H$. Note that on a daily or longer periods ground heat conduction (G) is negligible, making the surface energy, $Q (= R_n - G)$, available for latent and sensible heat fluxes equal to the net radiation term, R_n . This way their proposed “physically-based CR” model is only theoretical, having no practical value in its original formulation, and the authors admit it, recommending a real-world version of the CR at the end of their study.

Here the performance of their practical (i.e., when no surface temperature data is available, a common occurrence) CR formulation, i.e., Equations (6) and (16–18) in [1], is compared to the thermodynamics-based linear CR model of Crago et al. [4] and the polynomial CR version [5]. All three CR versions are single-parameter models, requiring the same input variables, working at the same spatial and temporal scales.

The aerodynamic resistance, r_a , in Equations (17–18) of [1] was estimated by the parameterization of [6]. The same parameterization was used for the wind function in [4,5]. Vegetation height as well as monthly values



of air pressure, temperature, vapor pressure deficit, wind speed, net radiation, ground heat conduction, (uncorrected) eddy-covariance (EC) LE fluxes came from FLUXNET [7] and were processed for analysis as described in [8] except that wind speed was not transformed to 2-m height value. The sole parameter, α_{YZ} in Equation (16) of [1], and the Priestley-Taylor α in [4,5] were globally calibrated (which means having the same parameter value for all stations and months) against the root-mean-square-error (RMSE) by a systematic brute-force ‘trial and error’ method over the 0.14–0.3 interval for α_{YZ} and 1.1–1.3 for α . The trial value of the parameter was incremented by 0.01 starting from the lower bound until the upper bound was reached. Figure 1 displays the resulting model performance against the EC-derived monthly LE values ($n = 1998$) of altogether 124 FLUXNET stations around the globe [8].

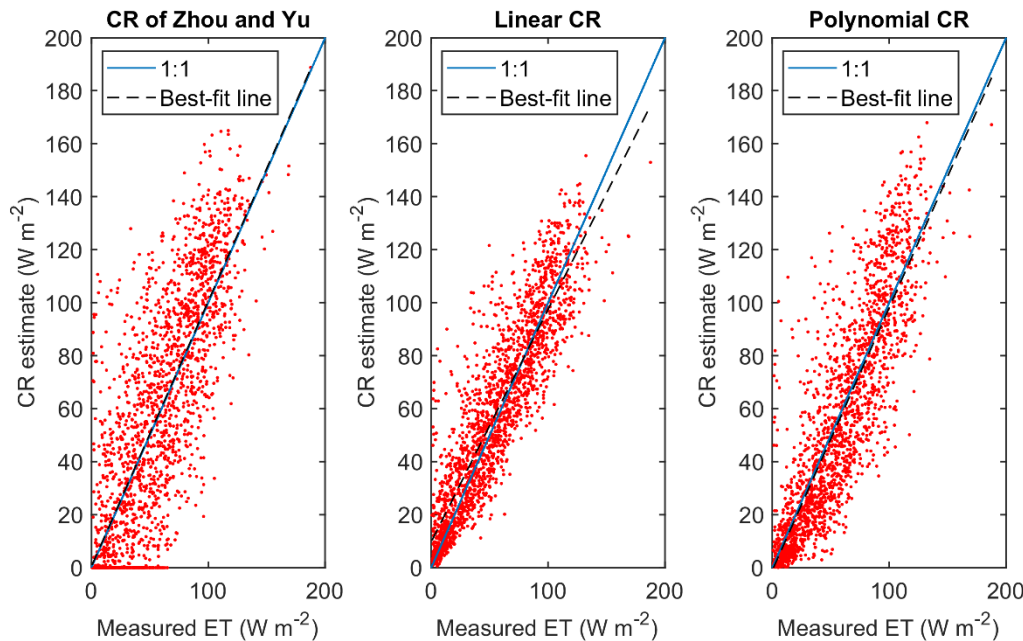


Figure 1. Model performance of the three globally calibrated monthly CR formulations. See Table 1 for performance statistics and [8] for model description, data availability and processing.

The thermodynamics-based CR models built on the criticized original Penman and Priestley-Taylor equations outperform the CR formulation of Zhou and Yu in almost every performance measure (Table 1), relative bias and best-fit slope being the exceptions. The linear CR has almost half the RMSE and double the NSE value of the CR version by Zhou and Yu. Note that all models use the same similarity-based parameterization [6] of the aerodynamic resistance and the corresponding wind function [4], therefore the significant difference in model performance between the Zhou and Yu version of the CR and the thermodynamics-based models must lie elsewhere. While the latter CR models evaluate PET_a with the constant available energy (Q) at the surface, the former does so at a much greater value (of Q/k' in Equation (18) of [1] where the adjustment parameter k' is less than unity). This greater value is needed to heat the normally cooler wet surface to the temperature of the drying land.

Table 1. Performance statistics of the three single-parameter CR model versions. R: linear correlation coefficient; RMSE: root-mean-square-error; RB: mean relative bias; MAE: mean absolute error; NSE: Nash-Sutcliffe model efficiency; SR: ratio of standard deviations; S: slope of the best-fit line.

CR Version	Parameter (-)	R (-)	RMSE ($W m^{-2}$)	RB (%)	MAE ($W m^{-2}$)	NSE (%)	SR (-)	S (-)
CR of Zhou and Yu	$\alpha_{YZ} = 0.15$	0.79	27.09	0.94	21.16	41.6	1.26	1.00
Linear CR	$\alpha = 1.12$	0.89	16.63	5.34	12.3	77.99	0.98	0.88
Polynomial CR	$\alpha = 1.2$	0.87	20.29	-2.71	15.19	67.24	1.14	0.99

While Zhou and Yu acknowledge that the wet patch surface temperature only ‘‘approximates its maximum value, i.e., the surface temperature of the surrounding area’’, there is no natural physical mechanism that would allow this to happen. In their approach the wet patch and the air over it have the same air, T_a , and surface, T_s , temperature as the surrounding drying area. This means there can be no advection of energy from the air toward the surface of the wet patch since $T_a < T_s$ over the drying land. The soil surrounding the wet patch likewise cannot

transport energy to the patch, since T_s is the same everywhere. In reality the wet patch must have $T_s < T_a$, allowing for an energy boost from the overpassing warmer air for its enhanced PET_a rate (relative to PET_e) made possible by moisture availability and air humidity still largely unaffected by the extra water vapor coming from the small wet patch.

As a result of the inflated energy requirement to raise the wet surface temperature to that of the surrounding drying land, the PET_a rates of Zhou and Yu become severely magnified in comparison to the energy-constrained PET_a values within the thermodynamics-based approach (Figure 2). The latter are so named because the radiation term of the Penman equation (corresponding to the first term in Equation (18) of [1]) is evaluated at Q rather than at Q/k' as Zhou and Yu suggest with a k' value less than unity. They even admit that by this inflated energy requirement the small wet surface becomes decoupled from its environment, at least from an energy-conservation point of view. Any error in the blown up PET_a and the corresponding adjustment parameter, k' , must also show up magnified in the ET estimates, likely leading to the observed increased scatter in Figure 1 and enlarged RMSE and diminished NSE values in Table 1.

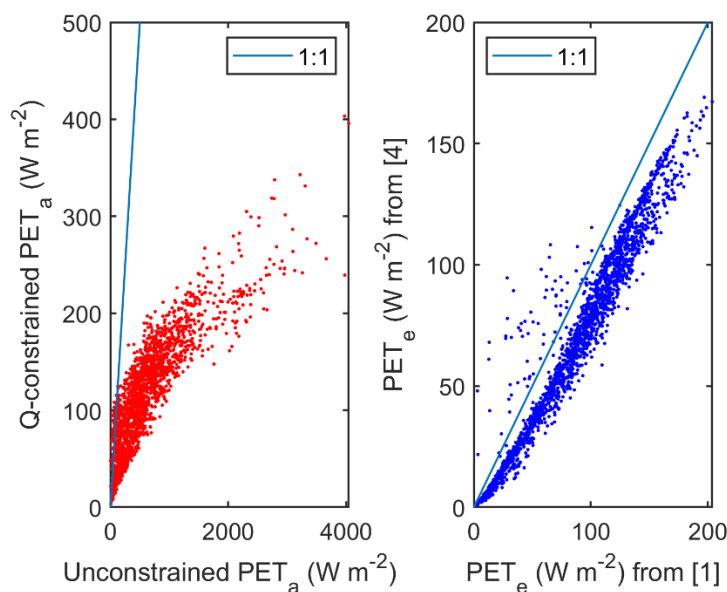


Figure 2. Comparison of the (i) unconstrained [1] and surface available energy (Q) constrained PET_a estimates [4] as well as; (ii) PET_e estimates of [1,4]. Note the magnitude difference in the PET_a values.

Another source of error in their CR formulation may come from the employment of the actual air temperature and vapor pressure deficit (VPD) in PET_e even if the latter is scaled back by k' , responsive to drying via T_a thus potentially counteracting the increasing VPD values during drying out of the environment. Measurements and thermodynamics indicate [9–11] that the temperature of the wet surface stays largely unchanged both in space and time under constant energy availability and so do VPD (over a wet surface of regional extent) and therefore PET_e , thus forming the very foundation of the complementary relationship as it capitalizes on the growing/shrinking difference between PET_a and this unchanging PET_e term during repeated drying/wetting cycles of the environment under the given Q .

In summary, the complementary relationship of evaporation is based on an intricate feedback mechanism between the drying land and the overlying atmosphere, driven fundamentally by thermodynamics in a weekly or longer temporal aggregation. In an attempt to improve existing CR models, Zhou and Yu decouple and arbitrarily change the value of the surface available energy from this elaborate feedback loop in order to create some idealistic conditions (such as that a wet patch should have the drying land surface temperature) and by doing so deteriorate the predicting power of the CR as demonstrated in this comment on their practical model formulation. A physically based CR model must be built on thermodynamics as exemplified by the linear and polynomial CR versions in this study, and can be expected to excel in model performance [12] over any other CR formulations.

Author Contributions

J.S.: conceptualization, methodology, software; J.S. and R.D.C.: data curation, writing—original draft preparation; J.S.: visualization, investigation; J.S.: software, validation; J.S. and R.D.C.: writing—reviewing and editing. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

All data were downloaded from the FLUXNET website (https://fluxnet.org/login/?redirect_to=/data/download-data/ (last access: 1 September 2023). The data and code used to process them are freely available through Zenodo at <https://doi.org/10.5281/zenodo.8172604>.

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Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

No AI tools were utilized for this paper.

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