Response to reviewer comments

We have already responded at length to the reviews by Han and Tian of the first draft of our comment (that earlier response starts on the following page of this document). We are not going to address all of the feedback provided in that review, but we do want to highlight some changes we made in the manuscript in light of their review.

1. In the introduction, in response to the review by Han and Tian of the draft of this comment, we removed the wording about different definitions of α and focused on the incorporation of advective effects in the sigmoid function.
2. In section 2, we addressed the role of empirical versus physically-based models as well as calibration. This topic was raised in the review by Han and Tian of the draft of this comment, and we felt it was appropriate to address it here.
3. In section 3, we discussed the argument made in the review by Han and Tian of the draft of this comment, namely that the flat part of the sigmoid curve only appears very near y_H=1.
4. In section 5, we changed the wording regarding how "normal" it is for wet advection to occur near y_H=1. At the end of the section we added two notes. First, an expression of the desirability of handling advection in a CR formulation, and then a note that advection plays an important role even for y_H<1.
5. In Section 6 we re-worded the summary of the argument in item 4 above.
6. We made multiple revisions to the reference citations.

Response to "Review of HESS-2020-310 'Comment on: A review of the complementary principle of evaporation: From the original linear relationship to generalized nonlinear functions by S. Han and F. Tian" (Reviews written by S. Han and F. Tian)

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Introduction

We thank S. Han and F. Tian for their thoughtful review (hereafter, "HT2020b") of our comment (hereafter, "CSQ2020") on Han and Tian (2020; hereafter "HT2020") and appreciate this continued discussion of the complementary principle (CP). In CSQ2020, we agreed that the Sigmoid Generalized Complementary (SGC) formulation is a serious development in CP research that deserves careful consideration and analysis. However, we concluded that it was not superior to other recent developments in the CP (e.g., Brutsaert, 2015; Crago et al. 2016; Crago and Qualls, 2018; Szilagyi et al., 2017, Ma and Szilagyi, 2019). HT2020b was structured around four claims, which we will discuss in order.

HT2020b Claim 1

HT2020b argue that two different approaches are both common and valuable in hydrology research. The first consists primarily of "calibrating parameters for the fitting of observed points and proposing a method to determine the parameters *in priori*." The second consists primarily of developing "approaches…carefully conducted on a physical basis." We agree--methods that consistently and accurately reproduce measurements are the most valuable. However, we find the second type of models to be more likely to generalize well and to apply well outside the validation range. We also acknowledge the reviewers' efforts as much as possible to ground their own research on a physical basis. We agree both methodologies should be explored, but would much prefer to proceed with physically-based approaches when possible.

HT2020b claim 2

Second, HT2020b address interpretation of the CP in conditions where large-scale advection or entrainment of free-atmosphere air partially disconnect the atmospheric boundary layer (ABL) from the condition of the surface. CSQ2020 argued that the CP is no longer valid under these conditions. That is, the logic of the CP requires that the ground and ABL are connected, so that the condition (temperature, humidity, wind speed, etc.) of the atmosphere is adjusted to the condition of the surface, particularly the availability of moisture at the surface. We agree that it is possible, in principle, to extend a method originally formulated as a CP equation so that it applies under conditions dominated by these large-scale conditions. Han and Tian (2018; hereafter "HT2018") attempt to do this by arguing that over wet surfaces actual regional evaporation E and Penman evaporation E_{pen} are nearly identical so that if E_{pen} is increased by dry advection, E would increase at essentially the same rate. We agreed in our comment that this is possible, but that it implies that the CP is invalid because the conditions in the ABL are disconnected from those at the surface. This brings the argument back to claim 1, because if the SGC works under these conditions, it is not because it captures the physical processes, but because it successfully matches the data.

HT2020b claim 3

In HT2020 and HT2018, experimental data from around the world are presented to demonstrate the existence of the three-stage pattern they advocate. CSQ2020 noted that other formulations, such as that of Brutsaert (2015) could also be said to have three comparable phases, and that the claim to have a horizontal upper (wet-surface) limit to the third stage is not supported by these data. HT2020b responded that the flat portion (derivative of zero) only strictly applies at a single point on the curve, so that graphs of data points would not necessarily reveal the flatness of the curve. This is a perfectly logical argument, but it means that the primary evidence for a proposed flat third-stage is not empirical but theoretical.

HT claim 4

The most powerful theoretical defense of the flat third stage of the SGP is found in HT2018, in which they derive slopes for the SGP curve at $x_{\min}$ and $x_{\max}$, the dry and wet limits, respectively. HT2020b wrote that the SGC equation can be expressed $E/E_{\mathrm{pen}}=f(E_{\mathrm{rad}}/E_{\mathrm{pen}}, m, n, x_{\min}, x_{\max})$, where E_{rad} is the first term of E_{pen}. But HT2020b stated that, in HT2018, $E_{\mathrm{rad}}/E_{\mathrm{pen}}$ was treated as the only independent variable, with the others as parameters. HT2018 and HT2020b were not obligated to include $x_{\min}$ as an important variable that can be calculated independently for each data point as proposed in our papers (Crago et al. 2016; Crago and Qualls, 2018; Szilagyi et al., 2017, Ma and Szilagyi, 2019). However, CSQ2020 noted that the assumption that $E_{\mathrm{rad}}/E_{\mathrm{pen}}$ was the only variable in f ruled out any version of our "rescaled" CP formulation. Incorporation of this variable $x_{\min}$ into the CP actually changes the functional form of the CP, which presumably could change the slope, particularly at the lower limit.

The first step in the derivation by HT2018 (after defining E/E_{pen} as a function of $E_{\mathrm{rad}}/E_{\mathrm{pen}}$ only) was to take partial derivatives of E with respect to E_{rad} and E_{aero} (i.e., the second term of E_{pen}), resulting in equation (17) of HT2018. CSQ2020 found this problematic because the process did not consider $x_{\max}$ (or $x_{\min}$, but we will focus on $x_{\max}$ in this paragraph) to be a variable in this process. The partial derivatives would have involved more terms, such as $(\partial E/\partial x_{\max})(\partial x_{\max}\partial E_{\mathrm{rad}})$ which would not be easy to analyze. Treating $x_{\max}$ as only a parameter resulted in (17). But later in the derivation, HT2018 claimed that $\partial x_{\max}/\partial E_{\mathrm{rad}}$ is not zero; this claim led directly to the flat third stage of the SGC curve. But CSQ2020 noted that, if $x_{\max}$ is a constant or parameter, this derivative must be zero. HT2020b responded that $x_{\max}$ was in fact treated as a parameter, not a variable, but also that "$x_{\max}$ is thought to vary with the environment," and "$x_{\max}$ is not independent of E_{rad}." These quotes seem to support the critique of CSQ2020 that $x_{\max}$ is treated as both a constant and as a variable in the same derivation. If $\partial x_{\max}/\partial E_{\mathrm{rad}}$ is not zero, then $x_{\max}$ must be treated as a variable when the partial derivatives are taken in the first step of the derivation.

To their credit, HT2020b do acknowledge that the limits to the CP are not well understood. Their surmise that this is due to the relative roles of advection and surface wetness at $x_{\max}$ seems plausible.

Summary

The CP is a fascinating concept. The principle can be stated in one or two sentences and in equations with only a few variables, but the application of the principle and interpretation of the variables is surprisingly complicated and some of the concepts are elusive. We have learned a great deal in thinking through the issues raised by these authors. We find at the end of this process that there are significant areas of agreement between us and HS2020b, and decreasing areas of disagreement. Specifically, we agree that both largely empirical and process-based approaches are valuable, and that large-scale advection must have an impact on the CP. But, while we appreciate the contributions of S. Han and F. Tian to this research, we still do not find arguments for the SGC formulation of the CP to be convincing.

References

Brutsaert, W. (2015). A generalized complementary principle with physical constraints for land-surface evaporation. *Water Resources Research*, 51(10), 8087-8093, doi:8010.1002/2015WR017720.

Crago, R. and Qualls, R. (2018). Evaluation of the Generalized and Rescaled complementary evaporation relationships. *Water Resources Research*, 54, 8086-8102. doi:10.1029/2018WR023401

Crago, R., Szilagyi, J., Qualls, R., & Huntington, J. (2016). Rescaling the complementary relationship for land surface evaporation. *Water Resources Research*, 52(11), 8461-8471. Doi:10.1002/2016WR019753

Han, S., & Tian, F. (2018). Derivation of a sigmoid generalized complementary function for evaporation with physical constraints. *Water Resources Research*, 54(7), 5050-5068. Doi:10.1029/2017WR021755

Han, S. & Tian, F. (2020). A review of the complementary principle of evaporation: from the original linear relationship to generalized nonlinear functions. *Hydrology and Earth System Sciences*, 24(5)2269-2285. Doi:10.5194/hess-24-2269-2020

Ma, N., & Szilagyi, J. (2019). The CR of Evaporation: A calibration-free diagnostic and benchmarking tool for large-scale terrestrial evapotranspiration modeling, *Water Resources Research*, 55(8), 7246-7274. Doi:10.1029/2019wr024867

Szilagyi, J., Crago, R., & Qualls, R. (2017) A calibration-free formulation of the complementary relationship of evaporation for continental-scale hydrology. *Journal of Geophysical Research: Atmospheres*, 122(1), 264-278.

Comment on: "A review of the complementary principle of evaporation: From the original linear relationship to generalized nonlinear functions" by S. Han and F. Tian

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Abstract

The paper by Han and Tian reviews the history of developments in the complementary relationship (CR) between actual and potential evaporation and introduces the generalized complementary principle (GCP) developed by the authors. This comment assesses whether the GCP: 1) Can give reasonable results from a wide range of surfaces worldwide; 2) is supported by experimental data that verify the three-stages of evaporation implicit in the GCP, particularly in the wet-surface limit; 3) has been proven to be correct by the authors in a previous paper; and 4) is supported by model studies showing that wet surfaces occur predominantly during periods of

large-scale moisture convergence. The assessment finds that arguments in favor of the GCP deserve to be taken seriously, but ultimately remain unconvincing.

1. Introduction

Han and Tian (2020) (hereafter HT20) provide important insights into the growing body of literature regarding the Complementary Relationship (CR) of evaporation, and serves well as an accessible review of the literature. The sigmoid formulation (their equation 13), a key feature of their Generalized Complementary Principle (GCP) (Han and Tian, 2018; hereafter HT18) is presented and defended in their paper.

Two of the present authors (Szilagyi and Crago, 2019, hereafter SC19) wrote an earlier comment critiquing the sigmoid function for violating established physical principles (see also the reply by Han and Tian, 2019a). After further consideration, the present authors recognize that the sigmoid curve proposed by ~~-~~HT18 and HT20 is intended to incorporate the effects of both the CR and of large-scale advection under wet-surface conditions. While we do not find the sigmoid function to have a strong theoretical or empirical basis, we agree with HT18 and HT20, at least in principle, that this need not violate any laws of nature. (Note that, unless otherwise indicated, all notation herein follows that of HT20.) ~~the Priestley and Taylor (1972) line at $x_H = E_{rad}/E_{Pen}=1/\alpha=1/1.26$ that appears in HT20 (their Figure 3), could be intended by HT18 and HT20 to mark a reference point on the graph, rather than to establish a limiting value that cannot be crossed. Unless otherwise noted, all notation herein follows that of HT20 – see also Tables I and II for notation and variable names. Also, the role of a related (but different) adjustable parameter (also named~~

~~α) seems to be used in the formulation primarily to adjust the shape of the sigmoid curve, rather than to set a limit on wet surface evaporation.~~

Table I Variables used

b	A GCP model parameter that adjusts the shape of the sigmoid function
E	Actual regional evaporation rate
E_{aero}	The second term of Penman's (1948) equation, related to the drying power of the air.
E^{max}_{MT}	Hypothetical maximum value of E that would occur from a wet patch in an otherwise completely desiccated region
E_{Pen}	Evaporation rate from Penman's (1948) equation
E_{PT}	αE_{rad} proposed by Priestley and Taylor (1972) for a wet regional surface with minimal advection
E_{rad}	The first term of Penman's (1948) equation, with the slope of the saturation vapor pressure typically taken at the measured air temperature (HT18, c.f., Slatyer and McIlroy ~~equivalent to the equilibrium evaporation rate of Slatyer and McIlroy~~ (1961)
E^{Tws}_{PT}	Value of E_{PT} found if the slope of the saturation vapor pressure curve is estimated at the wet surface temperature, T_{ws} (see Szilagyi et al., 2016)
$f(E_{rad}/E_{Pen})$	A hypothesized function of E_{rad}/E_{Pen}
x_H	E_{rad} / E_{Pen}
x_m	E^{Tws}_{PT} / E^{max}_{MT} the value of E^{Tws}_{PT} / E_{Pen} at which E goes to zero in the rescaled CR (Crago et al, 2016)
x_{max}	Parameter that sets the maximum value x_H can reach
x_{min}	Parameter that sets the value of x_H at which $y_H \to 0$
y_H	E / E_{Pen}

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α	The Priestley & Taylor (1972) parameter

Table II. Abbreviations

BC4	Boundary condition 4: $d(E/E_{pen})/d(E_{rad}/E_{pen}) = dy_H/dx_H \rightarrow 0$ as as $y_H \rightarrow 1$
CR	Complementary Relationship (between actual and potential evaporation) proposed by Bouchet (1963)
GCP	Han and Tian’s (2020) Generalized Complementary Principle
HT18	Han and Tian (2018)
HT20	Han and Tian (2020)
SC19	Szilagyi and Crago (2019)

The most controversial feature of the sigmoid function is the slope of the curve at the wet-surface limit. Namely, it requires that $d(E/E_{pen})/d(E_{rad}/E_{pen}) = dy_H/dx_H \rightarrow 0$ as as $y_H \rightarrow 1$ (hereafter, this boundary condition will be denoted “BC4”). That is, rather than a complementary relationship, BC4 requires that E and E_{Pen} are equal and that E exactly follows any variability by E_{Pen} in the wet surface limit.

BC4 deserves careful attention. A major purpose of this comment is to show that there are some indications such behavior can occur, but when it does it is a consequence of large-scale processes that disconnect the regional land surface from the overlying atmosphere, thus violating the basic assumptions behind the CR (namely, that atmospheric and surface conditions are tightly linked through surface fluxes). In light of this, corrections to the CR attempting to account for these ~~exceptional~~ cases will ~~inevitab~~likely result in a formulation that does not accurately represent ~~ordinary (~~minimally-advective~~)~~ conditions.

This comment will consider the evidence for the following four claims made by HT18 and HT20 in support of the sigmoid function and BC4: First, that the function works reasonably well to model evaporation from sites around the world; second, that data from these sites support a three-stage evaporation process and BC4, both of which are required by the sigmoid function; third, that HT2018 have provided a rigorous proof of the boundary conditions underlying the formulation; and fourth, that a partial explanation of BC4 has been provided by the study of Lintner et al. (2015).

2. Claim regarding modeling results

First, it is clear that the sigmoid function has been used successfully to model evaporation from flux stations around the world (see HT18). It is quite a flexible formulation that can match a wide range of data patterns on an (x_H, y_H) graph. Calibrated values of α and *b* published in HT18 (their Table 5) range from about 1.01 to 1.49 and from 0.59 to 17, respectively. Figure 1 shows the sigmoid function for the four combinations of these extreme parameter values (with x_{min}=0 and x_{max}=1). These show the wide range of possible curve shapes; allowing x_{min} and x_{max} to take other fixed values further increases the flexibility. Such an equation is likely to fit many datasets well, if tuning is permitted. ~~Of course, any~~ While we believe the ultimate goal of CR research should be a physically-based formulation ~~must ultimately~~that can work well without requiring local calibration of parameters, there is, nevertheless, value in formulations that can reliably match datasets with local calibration (including several of our respective publications).~~.~~

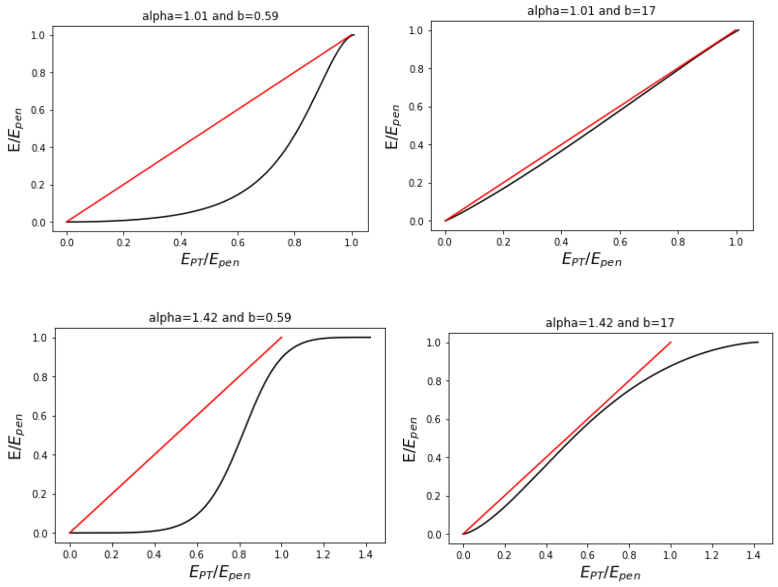

Figure 1. The sigmoid function (black curves) and the Priestley-Taylor line (α=1.26, straight line in red) for the most extreme parameter values documented in HT18. The scales of the horizontal axes differ.

3. Claim regarding empirical support for three evaporation stages and for BC4

Second, there does seem to be some empirical support for different slopes at different positions on (x_H,y_H) graphs (HT18, their Table 3). However, the curve proposed by Brutsaert (2015) also proposes a shallow slope for small y_H,(stage 1) a steep slope in the middle (stage 3), and a less steep slope near y_H=1 (stage 3). Similar behavior is also possible with the rescaled models of the present authors. The stage 3 slopes at large y_H values (HT18, Table 3) would be near zero according to BC4, but are generally near 1 instead. HT18 directly address BC4 with data in their Figure 6, which plots empirical data along with red curves resulting from the sigmoid function relating E/E_{PT} to E/E_{Pen}. The sigmoid function curves show E/E_{PT} increasing as E/E_{Pen} increases, until E/E_{PT} reaches a peak and then begins to decrease with further increases in E/E_{Pen}. Correlational evidence for this downturn is given by HT18, but the actual data plotted do not visibly follow the downturn in E/E_{PT} in either panel of Figure 6; the dramatic downturn in the red curve Figure 6(a) (the left panel) certainly is not matched by the data. While the limiting behavior would only be expected very near y_H=1, this very fact makes it difficult to argue that this behavior exists when nearly all data points on the graph fall below y_H=1. Similarly, some values of parameters for the sigmoid function make the flattening of the third stage nearly indistinguishable and therefore inconsequential (i.e., the top two panels of Figure 1).

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4. Claim regarding the derivation by HT18

Third, the derivation by HT18 is inconclusive. The derivation begins [HT18, their Eq. (8)]:

$$E = (E_{pen}) * f(E_{rad} / E_{pen}), \text{ where } E_{pen} = E_{rad} + E_{aero} \qquad (1)$$

where f is a function of (E_{rad}/E_{pen}). Partial derivatives of E were taken from Eq. (1) with respect to E_{rad} and E_{aero}. Further manipulations of these derivatives resulted in the four boundary conditions corresponding to the sigmoid curve (HT18). The function $f(E_{rad}/E_{pen})$ in Eq. (1) could include constants or parameters (for instance α, x_{min}, and x_{max}), whose “correct” values can be found by calibration, after which they must be treated as constants. This means that, once the parameters are determined, the shape of $f(E_{rad}/E_{pen})$ is also determined.

Unfortunately, this leads to two problems. First, the present authors' work with the "rescaled" CR (Crago et al., ~~2017~~2016, Szilagyi et al., 2017, Crago and Qualls, 2018) gives evidence that the variable $x_m = E^{Tws}{}_{PT} / E^{max}{}_{MT}$, ($x_m$ is our own notation) related to the value of $E^{Tws}{}_{PT} / E_{Pen}$ at which E goes to zero, is in fact a variable, not a constant. It must be calculated for each individual data point, and it results in a significant re-arrangement of the data. It could have been included in Eq. (1) by writing Eq. (1) as: $y_H = f(x_H, x_m)$. By taking derivatives without including the impact that a variable x_m might have, HT18 assumed from the beginning that E/E_{pen} does not vary with x_m, so a variable x_m boundary condition could not possibly arise from this derivation. On the other hand, if x_m is in fact a significant variable (as the papers cited above suggest), it could impact the entire derivation, but particularly the two dry-limit boundary conditions.

The parameter x_{max} is the maximum value x_H can reach, and is usually taken by HT18 and HT20 to be 1.26^{-1}, where 1.26 is the commonly-accepted value for the Priestley and Taylor parameter α. To prove that $dy_H/dx_H \rightarrow 0$ as $y_H \rightarrow 1$ (the most controversial finding of the derivation), HT18 had to show that $\partial x_{max}/\partial E_{rad}$ evaluated at y=1 cannot be 0 (see the paragraph starting at the bottom of page 5054 and ending at the top of page 5055 of HT18). But if Eq. (1) is true, x_{max} has to be treated as a constant, so the partial derivative must be 0. It is impossible for x_{max} to be a constant for the purpose of taking derivatives of Eq. (1), but a variable when evaluating $\partial x_{max}/\partial E_{rad}$. Thus, there is a logical inconsistency hidden in this derivation. SC19 showed that, if the Priestley-Taylor α (equivalent here to $1/x_{max}$) is actually a constant, HT18's derivation does not result in a specific required value for dy_H/dx_H at y=1. Thus, the boundary condition $dy_H/dx_H \rightarrow 0$ as $y_H \rightarrow 1$ does not follow from (1).

To sum up consideration of the derivation, three of the four boundary conditions (slope and intercept at the point where $y_H \rightarrow 0$, and slope as $y_H \rightarrow 1$) are doubtful due to the assumptions made when (1) was used as the definition of E.

5. Claim regarding support from the modeling study of Lintner (2015)

HT18 cite the modeling results of Lintner et al. (2015) in support of BC4. This study used a steady-state model that captured the key physical processes affecting evaporation. Model results show decreases in both E_{Pen} and E as soil moisture approaches saturation, similar to the behavior required by BC4. According to Lintner et al. (2015; see also HT18), large-scale horizontal moisture convergence decreases E_{Pen} by increasing atmospheric humidity, and at the same time it increases precipitation and thus soil moisture content. Near the wet limit, water availability matters less than E_{Pen} in determining E, so E and E_{Pen} decrease at the same rate. Thus, at the point of saturation, $E=E_{\mathrm{Pen}}$, and $\mathrm{d}(E/E_{\mathrm{Pen}})/\mathrm{d}(E_{\mathrm{PT}}/E_{\mathrm{Pen}}) = 0$, apparently satisfying BC4.

~~But note that the normal (i.e., minimal moisture convergence, divergence, or advection) behavior for a wet surface is~~CR researchers have long held that $E=E_{\mathrm{Pen}}=E_{\mathrm{PT}}$ for a wet regional surface (e.g., Brutsaert, 1982, 2005, 2015). The only way to get BC4-type behavior is to impose a large-scale process that causes E_{Pen} to differ from this value. That is, BC4 is not describing the drying process and the CR at all; rather, it is describing what happens when large-scale processes cause the CR ~~simply does not apply~~to break down. The scenario described by Lintner et al. (2015) requires a clear disconnect between the land surface processes and the overlying atmospheric conditions, violating the central assumption of the CR (e.g., Brutsaert, 1982, 2005).

It need not be the case that nearly-saturated surfaces coincide with moisture convergence in the real world~~outside of steady-state models~~. Nearly-saturated surface conditions can exist under a range of large-scale patterns, including positive, negative or negligible moisture convergence or advection. This is the case because soil moisture content varies at larger time scales than most other components of the surface water and energy budgets (e.g., Sellers et al, 1992), so nearly-saturated surface conditions can persist after a period of moisture convergence has ended. Furthermore, saturated surfaces can occur from other processes, such as thunderstorms driven by surface heating.

A formulation that can account for varying advection would be desirable, and such methods have been previously proposed (e.g. Parlange and Katul, 1992). As already discussed, evidence that the sigmoid curve does this successfully is lacking. Furthermore, it seems to address advective effects only for wet surfaces, while advection clearly affects drying surfaces as well.

6. Conclusions

HT18 and HT20 have martialed several empirical and theoretical arguments in support of their proposed sigmoid formulation of the CR. The range of arguments and data sources used is impressive, and the present authors only recently recognized the specific nature and the impact of this challenge to other CR formulations. There is little doubt that some aspects of their argument are true, including the ability of their formulation to match numerous experimental datasets. Nevertheless, the specific boundary conditions leading to the sigmoid function are not well-supported by empirical data; the derivation of the boundary conditions by HT18 was inconsistent regarding which model values are constants and which are variables; and the argument that large-scale processes require adoption of BC4 fails because it implies that ~~essentially makes~~ a disconnect between the land surface and the near-surface atmospheric conditions is the norm under near-wet-surface conditions, thus changing the shape of the CR with no solid theoretical or empirical arguments that it is in fact the norm.~~the exception (large-scale processes dominating land surface processes in determining near-surface atmospheric conditions) into the rule, and in doing so, it violates the assumptions of the CR. The CR should~~

~~ideally only be used under circumstances where advection is minimal.~~ Attempts to adjust for other conditions (e.g., Parlange and Katul, 1992) are possible, but should not over-ride consideration of the basic CR concept. This may require developing specific conditions for screening data.

There does not seem to be consensus in the research community on any of the boundary conditions of the CR except for x_H=1 when y_H=1. The current authors find the evidence for a variable x_m to be strong. This value can be calculated separately for each data point and it leads to a rescaling of the x_H-axis, and a resulting reduction in the scatter of the data points (Crago and Qualls, 2018).

While the sigmoid formulation is clearly the result of a serious and substantial research program, the difficulties with it described here are serious enough that we cannot see it as an improvement over other recent CR formulations.

References

Bouchet, R.: Epototranspiration reelle et potentielle, signification climatique, Int. Assoc. Hydrolog. Sci. Publ., 62, 134-142, 1963.

Brutsaert, W. (1982). *Evaporation into the Atmosphere: Theory, History, and Applications.* Dordrecht, Holland: D. Reidel .

Brutsaert, W. (2005). *Hydrology, An Introduction.* New York, NY: Cambridge University Press.

Brutsaert, W. (2015). A generalized complementary principle with physical constraints for land-surface evaporation. *Water Resources Research, 51*(10), 8087-8093. https://doi.org/10.1002/2015WR017720.

Crago, R. D., Qualls, R. J.: Evaluation of the generalized and rescaled complementary evaporation relationships, Water Resour. Res., 54, 8086-8102, 2018.

Crago, R., J. Szilagyi, R. Qualls, and J. L. Huntington (2016), Rescaling the complementary relationship for land surface evaporation, Water Resour. Res., 52, 8461–8470, DOI:10.1002/2016WR019753.

~~Crago R., Szilagyi, J., Qualls. R., and Huntington, J.: Rescaling the complementary relationship for land surface evaporation, Water Resour. Res., 52, 8461-8471, doi: 10.1002/2016WR019753, 2017.~~

Han, S. and F. Tian: Derivation of a sigmoid generalized complementary function for evaporation with physical constraints, Water Resour. Res. 54, 5050-5068, doi: 10.1029/2017WR021755, 2018.

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Han, S. and F. Tian: Reply to comment by J. Szilagyi and R. Crago on “Derivation of a sigmoid generalized complementary function for evaporation with physical constraints,” Water Resour. Res., 55, 1734-1736, doi:10.1029/2018WR023844, 2019a.

Han, S. and Tian, F.: A review of the complementary principle of evaporation: From original linear relationship to generalized nonlinear functions, Hydrol. Earth Syst. Sci., 24, 2269–2285, https://doi.org/10.5194/hess-24-2269-2020, 2020.

Lintner, B. R., Gentine, P., Findell, K. L., and Salvucci, G. D.: The Budyko and complementary relationships in an idealized model of large-scale land-atmosphere coupling, Hydrol. Earth Syst. Sci., 19, 2119-2131, 2015.

Parlange, M. B., Katul, G. G.: An advection-aridity evaporation model, Water Resour. Res, 28, 127-132, doi:10.1029/91WR02482, 1992.

Penman, H. L.: Natural evaporation from open water, bare soil, and grass, P. Roy. Soc. Lond. A, 193, 120-145, 1948.

Priestley, C. H. , and Taylor, R. J.: On the assessment of surface heat flux and evaporation using large-scale parameters, Mon. Weather Rev., 100, 81-92, 1972.

Sellers, P.J., Hall, F. G., Asrar, G., Strebel, D. E., and Murphy, R. E.: An overview of the First International Satellite Land Surface Climatology Project (ISLSCP) Field Experiment (FIFE), J. Geophys. Res., 97 No D17, 18345-18371, 1992.

Slatyer, R. O. and McIlroy, I. C.: Practical Microclimatology, Melbourne, Australia: CSIRO, 1961.

Szilagyi, J. and Crago, R.: Comment on “Derivation of a sigmoid generalized complementary function for evaporation with physical constraints” by S. Han and F. Tian, Water Resour. Res., 55, 868-869, doi: 10.1029/2018WR023502, 2019.

Szilagyi, J. Crago, R., and Qualls, R.: Testing the generalized complementary relationship of evaporation with continental-scale long-term water-balance data. J. Hydrol., 540, 914-922, doi: 10.1016/j.hydrol.2016.07.001., 2016.

Szilagyi, J., R. Crago, and R. Qualls, A calibration-free formulation of the complementary relationship of evaporation for continental-scale hydrology, *J. Geophysical Research Atmospheres*, 122, 264-278, doi: 10.1002/2016JD025611, 2017.

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