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 CSQ2020 argued that the CP is no longer valid under these conditions.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 $E/E_{pen}=f(E_{rad}/E_{pen}, m, n, x_{\min}, x_{\max})$, where E_{rad} is the first term of E_{pen}. But HT2020b stated that, in HT2018, E_{rad}/E_{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_{rad}/E_{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_{rad}/E_{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 $(\partial E/\partial x_{\max})(\partial x_{\max}\partial E_{rad})$ 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 $\partial x_{\max}/\partial E_{rad}$ 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 $\partial x_{\max}/\partial E_{rad}$ 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

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