Reply to interactive comment on Hydrol. Earth Syst. Sci. Discuss., 10, 13595, 2013.

***Authors' reply to "Interactive comment on* "Improving the complementary methods to estimate evapotranspiration under diverse climatic and physical conditions" *by* F. M. Anayah and J. J. Kaluarachchi" by Anonymous Referee #1**

Received and published: 7 January 2014

This paper proposed a complementary relationship model without calibration through the inter-comparison of CRAE, AA and GG model, as well as variations of them. The work is valuable because large number of FLUXNET sites were used for validation of CR model.

Reply: The authors would like to thank the anonymous reviewer for the time and effort made available to comment on the manuscript.

Major comments:

1. "This study aims to develop a calibration-free universal model using the complementary relationships to compute regional ET in contrasting climatic and physical conditions with meteorological data only". This purpose is very interesting.

However, I doubt that the proposed GG18 model may be not a "universal model". There are two methods on complementary relationship model. The first one is trying to give suitable estimates of ETp or ETw but keep the original complementary relationship (Eq. 1 or 8). This paper looks like the first one. The authors proposed several combinations of the equations, variables of the complementary relationship models. But there is little physical consideration about the definitions of ETp (or ETw) and the complementary relationship during the study. The results may be limited since there would be many other variations. For example, there may be other relationship except Eq. (1) or (8). It is only proved that GG 18 is the best between the 33 models used in this study. Please give more discussions about that GG18 is a "universal model" or not? Why?

Reply: The authors believe that the GG18 model is close to a "universal model." The GG18 model shows a better behavior among the 34 sites and its results are more consistent across the spectrum of climatic classes as shown in Figure 6. The ET estimates of the GG18 model for the moderate-climate sites are comparable to both those of wet or dry climatic classes (Figure 6), and the most recent ET studies (Table 6). None of the original (CRAE, AA and GG) methods, however, succeeded to estimate ET under sub-humid and Mediterranean climatic classes (see Table 2). The discrepancy is clear when compared to the more extreme conditions, i.e., dry and humid categories (Table 2).

As for the physical consideration about the definitions of ETW and ETP, the discussion in the paragraph starting line 25, page 15 gives some explanation. The authors used equations adopted by the original methods of CRAE, AA and GG in different ways. In the original CRAE and AA methods, their authors believed that the Priestley–Taylor equation can better estimate ETW. This contradicts with what the authors of the original GG method believed that is simply the Penman equation is superior is predicting ETW. In this study, it is meant not to explore all forms and formulae of ETP and ETW since the focus here is to developing a model for accurate predictions of actual ET. Therefore, formulae adopted in the original methods were selected only given that the methods supported the physical considerations of each definition.

As for the number of model variations, it is shown by Figure 3 that the trend in developing further model variations based on both the CRAE and AA methods is of less or no value than those based on the GG method. The largest possible number of model variations is considered in developing the 33 models originated from the basic complementary methods. Although some other formulae were neglected, yet this was justified by lessons learned from prior studies. For instance, Hobbins et al. (2001) found that changes to the AA method did not necessarily produce superior results especially by perturbing β (see page 15 lines 4-6). Therefore, the authors worked consistently in narrowing the number of model variations in a way that a comparison between variations can be plausibly and effectively made.

As for the complementary relationship represented by equations (1) and (8), those are the two formulae used by the original complementary methods. It is true that there could be more formulae developed to simulate the complementary relationship between ET, ETW and ETP, however, these formulae need to be calibrated to a specific location under specified conditions and this is contrary to the purpose of this study. It is a comparative study of "existing" equations of the different definitions recognized by the complementary methods.

Again, the authors are beleive that the results obtained by the GG18 model are encouraging and promising. This does not necessarily mean that further research cannot be conducted to make further improvements.

2. Other studies were trying to propose a better model and calibrate the parameters. According to the Granger and Gray's work, equation (8) is not comparable to equation (1), because equation (8) is just a rearrangement of the energy balance. The key of the GG model would be the function describing ET/ETp (equation 11 or 12). Is it possible that there are other parameters of Eq. 11 or 12, or other relationships describing ET/ETp? And the GG model performs better than GG18 with these relationships? I suggest more calibration work on the relationship (Eq. 11), or proposing a more universal relationship. The model with calibrated Eq. 11 may perform better than GG18.

Reply: Actually, equation 1 is a special case of equation 8 that occurs only when $\gamma = \Delta$ as indicated in page 8, line 12. The rate of change of saturation vapor pressure with temperature (Δ) is dependent on air temperature. Equation 8, therefore, makes the complementary relationship a function of air temperature. The value of air temperature at which $\gamma = \Delta$ can be back calculated and then concluded that equation (1) = equation (8) at that particular temperature.

The authors agree with the reviewer that equation 11 or 12 is of great significance to the results as it describes the ET/ETP relationship that influences the procedure to estimate actual ET. Yet, equations 11 and 12 were developed by Granger and Gray and there was no attempt to perform calibration in this study. The word "calibration" indicates validity to a given location or region and neglect the "universal" applicability. For this reason, the authors did not attempt to conduct any calibration to the equations proposed by the original methods.

3. AA and GG models are usually used at daily timescale, while the CRAE model is designed at monthly timescale. Since daily data is included in the datasets used in this study, I suggest that the AA and GG model should be calculated at daily timescales. If the AA and GG model is used using monthly data, the parameters may be changed. Please give some explanation or discussion.

Reply: The authors wanted to propose a universal ET model that can be successfully used for data deficit conditions under which daily data are missing or unavailable. It is believed that the regional estimates of ET entail monthly time resolution. The proposed GG18 model, however, was applied to a countrywide study of Ghana where daily data were available and the model performed well (Anayah et al., 2013). Monthly data from 2000 to 2005 were used for comparison with daily estimates of the GG18 model. The results suggest that the GG18 model can accommodate both daily and monthly time steps to produce consistent results. Please refer to Anayah (2012) and Anayah et al. (2013) given below for more details.

Specific comments to the authors:

1. There is no need to give Fig. 7. It would be more clearer if GG18 is given as E/ETPT=?

Reply: The ET/ETP relationship is given in the lower right-hand box as $ET/ETP = 2G_1 / (G_1+1)$. We will edit the manuscript as needed for further clarity.

2. It is better to list the mean value of ETpen, ETPT of the 34 sites in Table 1.

Reply: Table 1 is crowded enough to add additional information (or data) about each of the 34 sites. Furthermore, Table 1 serves as an introductory table that depicts the physical and climatic characteristics of each site and explains the reason for selecting these sites. In addition, the available EC-based actual ET data are given in Table 1 while ETpen and ETPT estimates represent potential, not actual, ET. This may cause confusion to the reader and therefore avoided. We will attempt to improve clarity in the revised manuscript.

References

Anayah, F.M., 2012. Improving complementary methods to predict evapotranspiration for data deficit conditions and global applications under climate change. PhD Dissertation, Utah State University, Logan, Utah, U.S.

Anayah, F.M., Kaluarachchi, J.J., Pavelic, P., Smakhtin, V., 2013. Predicting groundwater recharge in Ghana by estimating evapotranspiration. Water International 38(4), 408-432. DOI: 10.1080/02508060.2013.82164