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Reply on RC2

Zhaofei Liu

Author comment on "Accuracy of five ground heat flux empirical simulation methods in the surface energy balance-based remote sensing evapotranspiration models" by Zhaofei Liu, Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2022-125-AC2, 2022

Response (Referee #2 comment)

Ms. Ref. No.: hess-2022-125

Revised title: Accuracy of five ground heat flux empirical simulation methods in the surface energy balance-based remote sensing evapotranspiration models

Author(s): *Zhaofei Liu*

It would be greatly appreciated for your kind reviewing to this paper. Thanks very much for your valuable comments and suggestion. For your convenience to re-review the paper, the response corresponding to your comments are described in detail as follows:

This paper analyzes the relationship between G and Rn at a continental scale with hundreds of flux site measurements. This work is interesting to RS energy balance ET model users. It concluded that the linear coefficient (LC) method and the methods embedded with the normalized difference vegetation index (NDVI) were able to accurately simulate a half-hourly G series at most sites. The methods using fractional vegetation coverage showed poor performance. The highest accuracy was exhibited during sunrise periods (6:00-7:00), followed by sunset periods (17:00-18:00). The lowest accuracy was observed at noon periods (10:00-15:30). These conclusions are important for RS ET simulation. From this point, this work deserves a publication on HESS. Meanwhile, it also has some shortages which needs more clarification. The following are some comments.

Two major comments:

G was taken as the residual of Rn-H-LE in this paper, without considering the energy balance issue. This method might work for some low canopies which has a relative homogeneous land surface. The measurement of H and LE might have problem for forest site, since H and LE sensor are not high enough to be out of the sub-roughness layer on the canopy top. Hereby, this paper needs some discussion on why the energy unbalance item can be all partitioned to G, or what kind of data quality controlling process can make him/her believe that H and LE measurement at the selected sites are accurate and they don`t need energy balance correction.

Reply: Thanks for your valuable comments. The observation sites used in this study has a land cover classification. The sites were divided into seven land cover types: Forest, Grassland, Cropland, Wetland, Shrubland, Savanna, and Other types. Evaluations of seven land cover types have been added in revised manuscript. The low performance in some Forest sites might be due to the fact that the H and LE sensor are not high enough to be out of the sub-roughness layer on the canopy top as you mentioned.

As described in the second paragraph of the Introduction section, "G, which is the soil heat flux at the surface, is difficult to observe directly, due to technical limitations (Wang and Bou-Zeid, 2012; Gao et al., 2017), and direct estimation of G using RS data is not possible (Kalma et al., 2008; Allen et al., 2011; Saadi et al., 2018)." Therefore, as discussed in the first paragraph of the Discussion section, "The eddy covariance measurements of H and LE are generally considered to be the most accurate observations available. The Eq. (1) makes full use of the surface energy term that can be accurately measured at present. In other words, it assumes that the measurements of Rn, H and LE are accurate in this study."

Eq.2-6, the author has optimized a, a1, a2, and b. However, they did not analyze the values of these optimized variable. Figure 8 only show optimized values for three methods, without show other two methods. a1 and a2 in eq. 5 has their definition or physical meaning in the original publication. Whether the optimized values for these two parameters still follow the range of their physical meaning? I suggest to do some statistical analysis of these optimized parameter values. This can help other users when using equation 2-5. Chen et al. 2019 AFM has optimized fc based G/Rn equation. Please make a comparison with this study. They have optimized a1, a2 with a classification of land covers and canopy types. Since these parameter values could varies due to canopy covers, I suggest this paper also use canopy classification to analyze the NSE values in figure 6, KGE, RMSE, RE in figure 5, R^2 and slope in figure 3. Figure 1 can be also divided into different land covers. And, please also conclude which of the five methods is the best for which land covers or canopy classification. This result will be more useful for the RS ET model users. Figure 4, it would be interesting to analyze the linear fitting R^2 between G/Rn and NDVI for different canopy. The same problem with figure 7. Figure5, please also add Re, RMSE and KGE for other methods, not only show the LC method.

Reply: According to your valuable comments, the evaluations of seven land cover types have been added in revised manuscript. Figure 3, 4 and 7 (Figure 8 in the revised version) have been revised according to your valuable comments. A new Figure 7 has been added. Descriptions of these figures have also been added as follows,

Line 225-234, "In terms of seven land cover types, the intra-day performance of each land type was similar to that of all sites except the Other type (Fig. 3-c and 3-d). The correlation between G and Rn was relatively high in the sunrise and sunset periods. The correlation in Other and Wetland types is generally higher than that of other land cover types. In each period, the median R2 of all sites in the two types generally exceeded 0.60, and the highest value even exceeded 0.80. Except Other type, the difference of correlation between G and Rn in different land types is mainly reflected in the daytime period except Other type. The correlation in the Forest and Savanna types was significantly lower than that of other types during daytime, especially for Savanna sites, most of which had R2 lower than 0.5 during daytime. In Other type sites, the correlation between G and Rn in the daytime is stronger than that in the night periods. The slope value of each land cover type in the daytime is lower than that in the night. This intra-day distribution of slope was consistent with that of all sites."

Line 263-269, "In terms of seven land cover types, the intra-day performance of each land type was similar to that of all sites except the Other type (Fig. 3-c and 3-d). The correlation between G and Rn was relatively high in the sunrise and sunset periods. The correlation in Other and Wetland types is generally higher than that of other land cover types. In each period, the median R2 of all sites in the two types generally exceeded 0.60, and the highest value even exceeded 0.80. Except Other type, the difference of correlation between G and Rn in different land types is mainly reflected in the daytime period except Other type. The correlation in the Forest and Savanna types was significantly lower than that of other types during daytime, especially for Savanna sites, most of which had R2 lower than 0.5 during daytime. In Other type sites, the correlation between G and Rn in the daytime is stronger than that in the night periods. The slope value of each land cover type in the daytime is lower than that in the night. This intra-day distribution of slope was consistent with that of all sites."

Line 342-352, "Figure 7 shows the NSE simulated by each method in seven land cover types. The intra-day performance of each land cover type was similar to that of all sites except for the Other type, with the highest simulation accuracy at sunrise and sunset periods. The intra-day accuracy varied greatest at the Forest and Savanna sites. The median NSE of all sites simulated by the LC_NDVI_E method was close to 0.8 at the sunrise periods, while the corresponding NSE was only approximately 0.4. It varied little at other land cover types, especially for Wetland and Shrubland types. The greatest and lowest values of median NSE for all sites simulated by the LC_NDVI_E method were approximately 0.7 and 0.6, respectively. The NSE of the LC, LC_NDVI_P and LC_NDVI_E methods showed a unimodal distribution in the Other type sites. The NSE was significantly higher in the daytime than at night periods. The highest value was in the morning and noon periods, with the median NSE of all sites exceeding 0.8. The model performance was significantly better than other land cover types. In the Other type sites, the LC_NDVI_E method performed better than other methods, with the median NSE higher than 0.6 in each time period."

Line 378-389, "For different land cover types, the LC method performed better in the Cropland, Wetland and Other type sites. The mean value of median NSE of Wetland and Other sites was 0.66 and 0.69, respectively. The method was also able to accurately simulate G in the Forest, Grassland and Shrubland type sites, with the corresponding mean NSE of 0.57 or 0.56. It performed the worst at the Savanna sites, with the corresponding mean NSE was only 0.47. Since the Savanna sites are mainly distributed in tropical regions, this is consistent with the relatively poor performance of tropical region site as mentioned above. The performance of the method varied significantly in each land cover types except for the Other type sites. In the Wetland type sites, there were 3 sites in the United States with the NSE value lower than 0.3. The NSE of other 35 sites was higher than 0.50, with the highest value was close to 0.90. The Grassland sites were distributed in Asia, Europe, North America and Oceania. The NSE value was greater than 0.5 at each Grassland site in Europe. Cropland sites were distributed in Asia, Europe, and the United States. The NSE value was lower than 0.60 at 8 sites in the United States, with the mean NSE value of only 0.45. The method was able to accurately simulate G at 11 sites in Europe except for one site in Mediterranean region, with the mean NSE value of 0.74. The NSE for the two Asian sites was 0.54 and 0.71, respectively."

Line 480-481, a new sentence "This has also verified by Chen et al. (2019)." was added to make it clear.

In Figure 5, it was focus on some problems about the KGE, RMSE and RE in evaluating the model performance at different sites and time periods. However, the author would like to provide the land cover results of the KGE, RMSE and RE in the Supplementary Materials if possible.

Some minor comments:

Figure 6. The NSE value is calculated after or before a, a1, a2, b were optimized? The figure description should include this information.

Reply: Yes. The NSE value is calculated after the parameters were optimized. The figure title has been revised to "Figure 6: The NSE simulated by the (a) LC, (b) LC_NDVI_P, (c) LC_NDVI_E, (d) LC_fc_SE and (e) LC_fc_ST methods based on optimized parameters in each site and half-hour intervals." to make it clear.

Figure 8, the label for y-axis is not accurate, please revise it.

Reply: Yes. The label for y-axis in Figure 8 (Figure 9 in revised version) has been revised.

Figure 1a shows that G and Rn has a time phase difference in their diurnal variation. However, this paper does not consider this effect. Please explain why not consider this effect in their using G/Rn equations.

Reply: Yes. There is a time phase difference in the diurnal variation of G and Rn. The time phase difference varied at different sites. This effect has been reduced by parameter optimization at each site and half-hour period.

These ET datasets include, but are not limited to, the Breathing Earth System Simulator (BESS) (Jiang and Ryu, 2016), Moderate Resolution Imaging Spectroradiometer (MODIS; MOD16A2) (Mu et al., 2011), GLEAM (Miralles et al., 2011), and Numerical Terradynamic Simulation Group (NTSG) (Zhang et al., 2010) products. There are more global ET products which is based on energy balance method, such as EB-ET (Chen et al. 2021), http://data.tpdc.ac.cn/zh-hans/data/df4005fb-9449-4760-8e8a-09727df9fe36/?q=energy%20balance. This ET product is based on energy balance method. The author may think that this study is more useful for energy balance based ET models.

Reply: This sentence has been revised to "These ET datasets include, but are not limited to, the Breathing Earth System Simulator (BESS) (Jiang and Ryu, 2016), Moderate Resolution Imaging Spectroradiometer (MODIS; MOD16A2) (Mu et al., 2011), GLEAM (Miralles et al., 2011), Numerical Terradynamic Simulation Group (NTSG) (Zhang et al., 2010) and Thermal Energy Balance (Chen et al., 2021) products."

The surface energy balance method provides an alternative solution for assessing the G simulation schemes (van der Tol et al., 2012). This method could avoid the inconsistent spatial scale of G with that of LE and H in field measurements. I don`t understand what`s the meaning of these two sentences, please rephrase them.

Reply: As mentioned in Line 85-93, the gradient and calorimetry approaches had been used for evaluations of G simulations. These evaluations were limited to a single site scale because field observations of soil thermal properties were available only at a few sites. Therefore, the surface energy balance method provides an alternative solution for assessing the G simulation schemes (van der Tol et al., 2012). And this method could avoid the inconsistent spatial scale of G with that of LE and H in field measurements.

The slope and R2 of the linear fitting curve were -0.012 and 0.92, respectively. Are you sure the slope is negative value?

Reply: Yes. As shown in Figure 2-c, the slope of the linear fitting curve for mean G/Rn of all sites in the daytime periods is -0.012.

Change "use Rn to calculate G in the RS inversion of ET" to use Rn to calculate G in RS based energy balance ET models (Chen et al. 2019 AFM; Chen et al. 2021 JGR).

Reply: "use Rn to calculate G in the RS inversion of ET" has been revised to "use Rn to calculate G in the RS based energy balance ET models".

Some references about energy balance ET models should be cited:

Chen, X., et al. (2019). "Optimization of a remote sensing energy balance method over different canopy applied at global scale." Agricultural and Forest Meteorology 279: 107633.

Chen, X., et al. (2021). "Remote Sensing of Global Daily Evapotranspiration based on a Surface Energy Balance Method and Reanalysis Data." Journal of Geophysical Research: Atmospheres 126(16): e2020JD032873.

Chen, X., et al. (2014). "Development of a 10-year (2001–2010) 0.1° data set of land-surface energy balance for mainland China." Atmos. Chem. Phys. 14(23): 13097-13117

Reply: These references have been cited in revised manuscript.

Please also note the supplement to this comment:
https://hess.copernicus.org/preprints/hess-2022-125/hess-2022-125-AC2-supplement.pdf