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Discussions

Interactive comment on "Complementary Relationship for Estimating Evapotranspiration Using the Granger-Gray Model: Improvements and Comparison with a Remote Sensing Method" *by* Homin Kim and Jagath J. Kaluarachchi

Homin Kim and Jagath J. Kaluarachchi

homin.kim@aggiemail.usu.edu

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Reviewer comment 1. Why did they include the comparison with the remote sensing method? It serves no purpose. It certainly does not reveal what is wrong with the GG-NDVI method for wetter circumstances? This can solely be derived from comparison with the flux data. → There are two types of ET models and these are ground-based and remote sensing (RS)-based per McMahon et al. (2016). Among the ground-based ET models, GG-NDVI can be considered as one of the most effective ET models (Kim & Kaluarachchi, 2017). For RS-based ET, SSEBop is widely used and have been vali-

dated by many studies including USGS (Velpuri et al., 2013; Senay et al., 2013). Since 2016, USGS Geo Data Portal provides SSEBop ET data across the United States at 1-km resolution from 2000 to 2015. With advanced remote sensing techniques, RS-based ET models are gradually accepted as operational and effective compared to ground-based models. Therefore, the first objective of this study is the demonstrate the validity of the GG-NDVI model in comparison with this commonly used operational model, SSEBop. Accordingly, the GG-NDVI model showed similar accuracy or even better results than the SSEBop model. The major reason to move from GG-NDVI to Adjusted GG-NDVI is because certain results still showed questionable shift (see Figure 7). A careful investigation showed the cause of this departure is the assumption of linear complementary relationship. When we removed this linear assumption with an appropriate nonlinear function f(G), the results improved dramatically confirming the fact that the linear assumption is not always valid. As the reviewer mentioned, the limitation of the symmetric relationship was derived from comparison with flux data, and the subsequent model, Adjusted GG-NDVI, was validated using the remote sensing method. In brief, both GG-NDVI and Adjusted GG-NDVI were validated using SSEBop and the results indicated that the Adjusted GG-NDVI model can provide accurate ET estimations under diverse climate conditions while producing better results than SSEBop.

Reviewer comment 2. It seems that the only incremental advance in the paper is the f(G) function that corrects for wetter circumstances. This seems to warrant a technical note only, whereby many parts of the paper (derivation of the GG-NDVI method, all the remote sensing stuff, as well as the review of methods in the introduction) are unnecessary. → We found the limitation of GG-NDVI from Figure 7 and this limitation is related to the symmetric relationship between ET and ETP or (ETW). The question of symmetry of the complementary relationship was raised by prior researchers as well (Kahler & Brutsaert, 2006; Venturini et al., 2011). Therefore, we were not ready to move ahead with the GG-NDVI as the final model as the results showed questionable behavior under selected conditions. Therefore, as mentioned earlier, Adjusted GG-

NDVI is the resulting and improved model. Note we found the weak performance of GG-NDVI with increasing G from the Figure 7. The corresponding correction function, f(G), was developed using 2,772 data points from 60 flux sites covering wide range of conditions. As a result, the Adjusted GG-NDVI model performed well for all 60 sites. With the introduction of the correction function f(G), our understanding of the complementary relationship increased significantly while providing much improved and accurate ET estimates.

Reviewer comment 3. The f(G) function itself is not based on sound physical reasoning. In Phase 1, changing NDVI values over time are said to cause the larger errors, while in Phase 2 it is said that even at saturation E will remain smaller than EW and EW is increased. i.e. by multiplying with a function f(G) that is empirically determined and thus necessary includes many effects. → Within the complementary relationship, ETW is not increased by using f(G). Theoretically, the symmetric relationship will be changed. Exclusion of f(G) in Eq. (19) brings it back to the original form of the complementary relationship. The value of '2' denotes the symmetric relationship between ET and ETP while f(G) removes this assumption and make it nonlinear. Using f(G) in Eq. (19) means that there is no exact shape for the relationship between ET and ETP. As we mentioned in the manuscript, the nonlinear exponential function was used because the difference between ET and ETW (or ETP) decreases exponentially with increasing wetness and the approach used here is similar to the study of Kahler & Brutsaert (2006).

Minor comment. The authors state that the GG model is not suitable for drier circumstance because it was only tested for wetter circumstances in Canada. But that is not what is said in the Granger-Gray 1989 paper. In fact, the opposite! First, they refer to the data coming from the semi-arid climate zone of Western Canada. Second, if one looks at Figure 2 in that paper we see that the relationship is fitted to G values smaller than 0.6, which means it is most suitable for dry circumstances. → The climate conditions such as semi-arid, wet, and dry depend on the definition of dryness index. As the reviewer mentioned, Granger & Gray (1989) derived G parameter using field data mon-

itored at two stations, Bad Lake and Saskatoon, located in a semi-arid climatic zone of Western Canada. However, according to the data of Centre for Hydrology in University of Saskatchewan (http://www.usask.ca/hydrology/index.php), it can be clearly seen that Saskatoon is a cold region, exhibits classical cold regions hydrology with continuous snow cover from October to April and many lakes and wetlands are present in the central and eastern parts. Furthermore, studies of Anayah & Kaluarachchi (2014) and Xu & Singh (2005) demonstrated that Granger and Gray (1989) model worked well in humid regions and become worse for arid regions. They also suggested that using calibrated parameter values can improve the model performance. Thus, the relative evaporation parameter, G, needs to be upgraded.

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