Supplemental Material

Journal of Hydrometeorology

Uncertainties Caused by Resistances in Evapotranspiration Estimation Using High-Density Eddy Covariance Measurements

https://doi.org/10.1175/JHM-D-19-0191.1

Supporting information for

Uncertainties caused by resistances in evapotranspiration estimation using high-density eddy covariance measurements

Wen Li Zhao[1, 2], Guo Yu Qiu[1], Yu Jiu Xiong[3, 4], Kyaw Tha Paw U[4], Pierre Gentine[2], Baoyu Chen[5]

[1]School of Environment and Energy, Peking University Shenzhen Graduate School, Peking University, Shenzhen 518055, China

[2]Department of Earth and Environmental Engineering, Columbia University, New York, New York, 10027, USA

[3]School of Civil Engineering, Sun Yat-Sen University, Guangzhou 510275, Guangdong, China

[4]Department of Land, Air and Water Resources, University of California at Davis, Davis 95618, USA

[5]Research Institute of Agricultural Resources and Environment, Jilin Academy of Agricultural Sciences, Key Laboratory of Plant Nutrition and Agro-Environment in Northeast Region, Ministry of Agriculture, Changchun, Jilin, China

Correspondence to: Yu Jiu Xiong (xiongyuj@mail.sysu.edu.cn)

A brief description of the three-temperature (3T) model

The 3T model, which was first developed by Qiu (1996), is derived from the energy balance and is loosely related to the three-leaf model of Paw U and Daughtry (1984). A reference temperature (i.e., a dry surface without evaporation or transpiration) is used to eliminate the impacts of latent heat and surface resistance on water vapor in the energy balance equation under the assumption that r_a for the reference soil is the same as that for other soil surfaces (Qiu et al., 1998, 2006), resulting in Eq. (S1) for soil evaporation (E_s) and Eq. (S2) for vegetation transpiration (E_c); this characteristic is unique to the 3T model. Thus, when estimating evapotranspiration (ET), the estimation process does not explicitly include any resistance parameterizations. As a result of this unique feature, the 3T model is different from other ET estimation methods that require resistance data, such as the PM equation. Total ET is the sum of the E_s and E_c (Eq. S3). Detailed descriptions of the deduction of the 3T model can be found in Qiu (1996) and Qiu et al. (1998, 2006).

$$LE_s = R_{n,s} - G_s - \left(R_{n,sr} - G_{sr}\right)\frac{T_{0s} - T_a}{T_{0sr} - T_a} \tag{S1}$$

$$LE_c = R_{n,c} - R_{n,cr}\frac{T_{0c} - T_a}{T_{0cr} - T_a} \tag{S2}$$

$$L\left(ET\right) = LE_s + LE_c \tag{S3}$$

where L is the latent heat of vaporization in J kg^{-1} K^{-1}; R_n and G are the net radiation and soil heat flux, respectively in W m^{-2}; T_a is the air temperature in K; and T_{0s} and T_{0c} are the temperatures (K) of the soil and vegetation components, respectively. The subscripts "*s*" and "*c*" indicate the soil and canopy components, respectively, whereas "*sr*" and "*cr*" represent the reference dry soil and reference dry canopy, respectively.

Its unique features make the 3T model a relatively simple method for remote sensing applications (Xiong & Qiu, 2011, 2014; Xiong et al., 2015; Wang et al., 2016), in which pixel attributes (specifically, soil, vegetation or combinations of both) can be determined using the normalized difference vegetation index (NDVI) and its maximum and minimum thresholds (Xiong et al., 2015). Detailed parameterizations of the model inputs can be found in Xiong & Qiu (2014) and Xiong et al. (2015, 2019).

In this study, daytime flux observations from 17 flux towers deployed inside the oasis over an area covering 5.5 km × 5.5 km were used as model inputs (see Section 2.2 and Table S1 for details) (Liu et al., 2016). EC system number 19 (Shenshawo), which was installed in sandy desert outside the oasis, was adopted as the dry reference surface. In this case, the observed net radiation, soil heat flux, air temperature, and land surface temperature from EC system number 19 (sandy desert) were used as reference values for the other flux towers, and the other inputs of the 3T model were from each observation tower by assuming the area is homogenous. In addition, because the soil heat flux (G) may not be negligible compared to the net radiation (Rn), with a mean ratio of 16% (G/Rn) for vegetated areas, the LE values were estimated using a modified Eq. (S2) by subtracting G from $R_{n,c}$.

Table S1. Details of the 17 EC systems in the key experimental area shown in Fig. 2c.

EC ID	Sensor type & manufactures	Sensor height (m)	Observation duration in 2012	Surface condition	LAI ($m^2\ m^{-2}$)	Soil moisture (%)
1	Gill/Li7500A, Gill, UK/Li-cor, USA	3.8	Jun. 16 to Sep. 17	vegetable field	1.83	36.04
2	CSAT3/Li7500, Campbell/Li-cor, USA	3.7	Jun. 15 to Sep. 21	maize	2.49	20.73
3	Gill/Li7500A, Gill, UK/Li-cor, USA	3.8	Jun. 25 to Sep. 18	maize	2.35	36.57
4	CSAT3/Li7500A, Campbell/Li-cor, USA	4.2 (6.2 after Aug.19)	May 31 to Sep. 17	residential area	−	18.65

5		3	Jun. 3 to Sep. 18	maize	2.50	29.83
6		4.6	May 28 to Sep. 21	maize	2.39	31.57
7		3.8	May 29 to Sep. 18	maize	2.41	29.59
8		3.2	May 28 to Sep. 21	maize	2.58	31.53
9	Gill/Li7500A, Gill, UK/Li-cor, USA	3.9	Jun. 25 to Sep. 17	maize	3.42	35.99
10		4.8	Jul. 5 to Sep. 17	maize	2.62	30.14
11		3.5	May 29 to Sep. 18	maize	2.26	27.12
12	CSAT3/Li7500, Campbell/Li-cor, USA	3.5	May 28 to Sep. 21	maize	2.44	20.82
13		5	May 27 to Sep. 20	maize	2.27	22.62
14		4.6	May 30 to Sep. 17	maize	2.53	21.83
15		4.5	May 25 to Dec. 30	maize	3.14	28.45
16	Gill/Li7500, Gill, UK/Li-cor, USA	4.9	Jul. 2 to Sep. 17	maize	2.61	28.76
17	CSAT3/EC150, Campbell, USA	7	May 31 to Sep. 17	orchard	1.65	28.90

Note: 1. All of the sensor types are open-path, and related information was cited from Liu et al. (2016);

2. The sampling frequency of the EC systems was 10 Hz, and the EC data were post processed, quality controlled, recorded every 30 min on average by Liu et al. (2016) and distributed by the HiWATER project;

3. LAI and soil moisture values were averaged using corresponding data provided by the HiWATER project.

References

Liu, S. M., Xu, Z. W., Song, L. S., Zhao, Q. Y., Ge, Y., Xu, T. R., Ma, Y. F., Zhu, Z. L., Jia, Z. Z., and Zhang, F.: Upscaling evapotranspiration measurements from multi-site to the satellite pixel scale over heterogeneous land surfaces, Agric. For. Meteorol., 230, 97–113, https://doi.org/10.1016/j.agrformet.2016.04.008, 2016.

Paw U, K. T. and Daughtry, C. S. T.: A new method for the estimation of diffusive resistance of leaves, Agric. For. Meteorol., 33, 141–155, https://doi.org/10.1016/0168-1923(84)90066-2, 1984.

Qiu, G. Y., Shi, P. J., and Wang, L. M.: Theoretical analysis of a soil evaporation transfer coefficient, Remote Sens. Environ., 101, 390−398, https://doi.org/10.1016/j.rse.2006.01.007, 2006.

Qiu, G. Y., Yano, T., and Momii, K.: An improved methodology to measure evaporation from bare soil based on comparison of surface temperature with a dry soil, J. Hydrol., 210, 93−105, https://doi.org/10.1016/s0022-1694(98)00174-7, 1998.

Qiu, G. Y.: A new method for estimation of evapotranspiration, Doctoral dissertation, the Unite Graduate School of Agricultural Science, Tottori University, Japan, 1996.

Wang, Y. Q., Xiong, Y. J., Qiu, G. Y., and Zhang, Q. T.: Is scale really a challenge in evapotranspiration estimation? A multi-scale study in the Heihe oasis using thermal remote sensing and the three-temperature model, Agric. For. Meteorol., 230–231, 128–141, https://doi.org/10.1016/j.agrformet.2016.03.012, 2016.

Xiong, Y. J. and Qiu, G. Y.: Estimation of evapotranspiration using remotely sensed land surface temperature and the revised three-temperature model, Int. J. Remote Sens., 32, 5853–5874, https://doi.org/10.1080/01431161.2010.507791, 2011.

Xiong, Y. J. and Qiu, G. Y.: Simplifying the revised three-temperature model for remotely estimating regional evapotranspiration and its application to a semi-arid steppe, Int. J. Remote Sens., 35, 2003–2027, 2014.

Xiong, Y. J., Qiu, G. Y., Zhao, S. H., and Tian, F.: An evapotranspiration product for arid regions based on the three-temperature model and thermal remote sensing, J. Hydrol., 530, 392–404, https://doi.org/10.1016/j.jhydrol.2015.09.050, 2015.

Xiong, Y. J., Zhao, W. L., Wang, P., Paw U, K. T., and Qiu, G. Y.: Simple and applicable method for estimating evapotranspiration and its components in arid regions. J. Geophys. Res.-Atmos., 124, 9963– 998, 2019.