Comparison of energy balance values estimated with METRIC model with eddy covariance data for soybean and maize in irrigated and rainfed systems.

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Abstract

This study assessed the performance of the METRIC model for estimation of instantaneous actual evapotranspiration and energy balance components in dry and humid years for soybean and maize, under irrigated and rainfed environments in northeastern of Nebraska. Eddy covariance energy and mass fluxes from three AmeriFlux Nebraska were used to compare METRIC estimates during four growing seasons (twenty one scenes). Additionally, energy balance closure for each day was analyzed. The influence of the reference ET on estimates was investigated. Reference ET for grassland (ETo) and an alfalfa (ETr) were used in METRIC to estimate actual ET. Results indicate that energy balance closure for the estimated fluxes was poor. A linear regression between the sum of net radiation and soil flux (Rn + G) to the sum of sensible and latent heat fluxes (H + LE) yielded a slope of 0.75, intercept of 55.6 and R^2 = 0.76. METRIC overestimated actual ET, but results differed depending on the reference ET used (RMSE = 1.66 mm d^{-1} and 0.97 for ETr and ETo respectively). Estimation of sensible heat flux was poor (RMSE = 92 W m^{-2}), while net radiation (Rn) and soil flux (G) were acceptably estimated (RMSE of 63 and 42 W m^{-2} respectively). Errors in actual ET estimated for METRIC could be attributed to bias in actual ET measure with eddy covariance or reference ET used in METRIC. These results suggest that would be necessary study which reference ET is more appropriate to use within METRIC depending on the climatic zone.

Key words: evapotranspiration, remote sensing, Landsat.

1. Introduction

Quantifying the consumption of water over large agricultural areas and within irrigated systems is essential for water resources planning; essentially in dry areas used for crops or grasslands. Actual evapotranspiration (ETa) combines plant transpiration and soil evaporation fluxes. ETa has been measured with lysimeter, bowen ratio, or eddy covariance methods. All methods provide punctual estimation of ETa and involve high costs. Traditionally, ETa has been calculated using crop coefficient (Kc) multiplied by potential evapotranspiration (Allen et al., 1998).

Remote sensing tools applied to quantify the amount of water used for crop have emerged after the 90' (Bastiaanssen et al., 1998). Remote sensing tools used to predict actual evapotranspiration in large crop areas are both: powerful and inexpensive. Actual evapotranspiration is highly variable in space on crop areas, therefore this technique also allows the quantification of spatial variability on evapotranspiration (Irmak et al., 2011). Additionally, this methodology does not require knowing species, crop stage, and crop characteristics (vegetation density) which requires time consuming measurements.

METRIC is probably the best known model of the models in the family of residual surface energy balance (RSEB). METRIC uses the SEBAL technique to estimate surface temperature gradient (dT) as a lineal function of radiometric surface temperature provided by satellite images (Allen et al. 2007a, Allen et al. 2007b).

Therefore, the aim of this work was to evaluate the performance of the METRIC model for the estimation of instantaneous actual evapotranspiration and energy balance fluxes for a dry and humidity year, for soybean and maize, under irrigated and rainfed environments in northeastern of Nebraska.

2. Material and Methods

2.1. Study area and whether data

The study was performed in Ameriflux sites in Nebraska, USA: USNe1(latitude: 41°09'54.2''N, length 96°28'35.9''W, altitude 361m), USNe2 (latitude: 41°09'53.5''N, length 96°28'12.3''W, altitude 362m), USNe3 (latitude: 41°10'46.8''N, length 96°26'22.7''W, altitude 362m). Sites USNe1 and USNe2 are equipped with center pivot irrigation, and USNe3 site is a rainfed. All sites were managed with continuous crop under no-till systems. USNe1 is a continuous maize site, meanwhileUSNe2 and USNe3 are maize-soybean rotations. This study was executed during dry (2004 and 2013) and humid (2007 and 2010) years.

. Hourly Penman-Monteith reference evapotranspiration (ETr) was calculated (ASCE-EWRI 2005) using data from the eddy covariance tower. Energy flux measurement was measured with eddy covariance methodology in each site and compared with energy flux predicted with METRIC. Observed values for each energy flux data point corresponded on average to the satellite overpass within a three hour window.

We used RefET Version 3.1.15 software of the University of Idaho (Allen, 2012) to calculate hourly ETr. Whether station height in soybean was three meters, but it was changed from three to six meters when crop reached one meter in maize.

2.2. Satellite data

All free cloud scenes (Path 28, Row 31) were selected during summer crop growing seasons for the years 2004, 2007, 2010 and 2013. The images were downloaded fromUSGS EROS (http://landsatlook.usgs.gov/viewer.html). Satellite images of Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM +) and Landsat 8 Operational Land Imager (OLI) were used. Images used were: DOY: 186, 234, 242, 282, 298 in 2004; 130, 186, 202, 242, 250 in 2007; 122, 194, 234, 242, 258, 274, 290 in 2010; 154, 202, 242, 298 in 2013.

2.3. METRIC™algorithms

The model was implemented according to Allen et al. (2010). Actual evapotranspiration (ETa) was computed into METRIC model as a residual of the surface energy balance (Allen et al., 2007). The following equation to calculate ETa was used:

$$\lambda ET = LE = Rn - H - G \quad (1)$$

where λ is the latent heat of vaporization (J kg^{-1}), ETi is actual evapotranspiration (mm h^{-1}), LE is latent heat flux (W m^{-2}), Rn is net radiation (W m^{-2}), H is sensible heat flux (W m^{-2}), and G is soil heat flux (W m^{-2}).

MTERIC estimated ETa as a fraction of reference evapotranspiration from alfalfa (ETrF), considering ETrF constant throughout the day as described by Allen et al. (2007).

Actual Rn is estimated by subtracting all outgoing radiant fluxes from all incoming radiant fluxes and including solar and thermal radiation, following equation:

$$Rn = R_{Sin} - \alpha R_{Sin} - R_{Lin} - R_{Lout} - (1- \varepsilon_0)R_{Lin} \quad (2)$$

where R_{Sin} = incoming short-wave radiation (W m^{-2}), α = surface albedo, R_{Lin} = incoming long-wave radiation (W m^{-2}), R_{Lout} = outgoing long-wave radiation (W m^{-2}), and ε_0= broad-band surface thermal emissivity.

The amount of soil heat flux (G) transfer by conduction is computed using an empirical equation proposed by Bastiaanssen (2000):

$$G / Rn = (T_S - 273.15)(0.0038 + 0.0074\alpha)(1 - 0.98\ NDVI^4) \quad (3)$$

METRIC represents sensible heat flux (H) interchange by a linear equation between temperature difference in two heights and aerodynamic resistance (Allen et al., 2007). H is computed through the following equation:

$$H = \rho_{air} C_p \frac{dT}{ra} \tag{4}$$

where ρ_{air} = air density (kg m^{-3}), C_p = specific heat of air at constant pressure (J kg^{-1} K^{-1}), and ra = aerodynamic resistance (s m-1), dT = near surface temperature difference between two heights.

The values dT and ra in equation 4 are unknown and these values are internally calibrated for two extreme conditions (dry and humid), using hot and cold pixels. We used internal calibration according to process described by Allen et al. (2007). Pair of cold and hot pixels from agricultural areas within a 30 km perimeter from wheatear station were used. For cold and hot pixels instantaneous values of H were calculated as:

$$H_{cold} = R_{n\_cold} - G_{cold} - 1.2ETr \tag{5}$$

$$H_{hot} = R_{n\_hot} - G_{hot} \tag{6}$$

where subscript "cold" and "hot" indicate each energy flux for the cold and hot pixels, and ETr is reference evapotranspiration from alfalfa at the time of satellite overpass. Additionally a factor of 1.2 was extracted from Tasumi (2003). In addition, in the hot pixel the soil energy balance to adjust ETrF was used.

For each image used we compared, estimated and measured values through regression analysis, evaluating determination coefficient (R2), and root mean square error (RMSE). As estimated values for METRIC we used twenty five pixels of the area surrounding the weather station.

$$\text{Bias} = \Sigma\, Di \,/\, N \tag{7}$$

$$\text{RMSE} = \sqrt{}\, (Yi - Y)^2 \,/\, N \tag{8}$$

where N is total number of situations, $Di = Yi - Y$, Yi is observed value at point i, Y corresponds to estimated value by model at point i.

3. Results and Discussion

Figure 1 shows the energy balance closure for satellite overpass time, suggesting that fit was poor (RMSE=90 W m-2, slope of lineal regression of 0.76 and R^2 = 0.76). This indicates that latent heat flux measured with the eddy covariance method was not absolutely accurate. Wilson et al. (2002) found a slope of lineal regression between 0.55 to 0.99, and the mean imbalance was in the order of 20%.

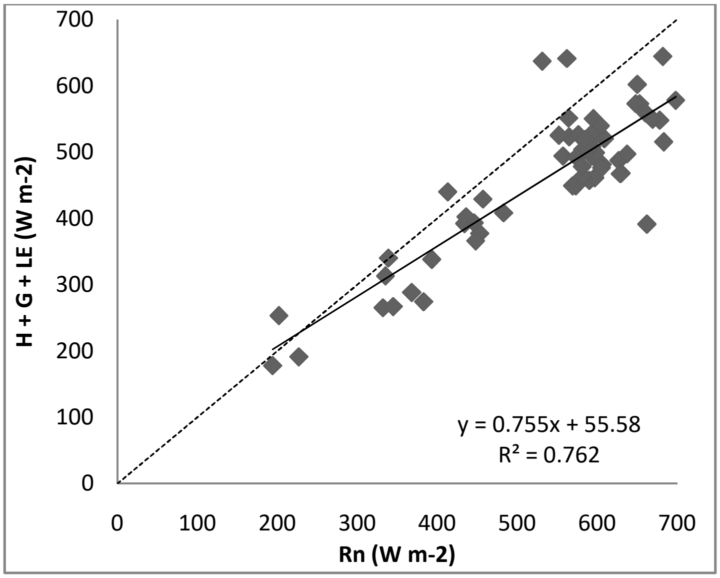

Figure1. Surface energy balance closure based on average among three hours fluxes of net radiation (Rn), soil heat (G), sensible heat (H) and latent heat (LE) during overpass times of Landsat scenes for each images available.

The comparison between estimated values by METRIC and measured values by AmeriFlux for each component of energy balance are presented in Figure 2. Most of the points in Rn and G were distributed around 1:1 line (RMSE of 63 and 42 W $m^{-2}$and rRMSE of 12 and 54% for Rn and G respectively). While the range of sensible heat flux in METRIC, and AmeriFlux were between -50 – 350 W m^{-2}, but sensible heat flux was the component of energy balance that showed the highest scattering from line 1:1 (RMSE = 92 W $m^{-2}$and rRMSE =70%). METRIC overestimated ET compared to eddy covariance (RMSE = 1.66 mm $d^{-1}$and Bias = 1.2mm d^{-1}). These results are in agreement with Carrasco-Benavides et al. (2013) which found that METRIC overestimated ET in vineyards when ET measurement was from eddy covariance. This errors could be due to eddy covariance underestimation of actual ET, or due to the choice of reference ET (alfalfa) used in METRIC.

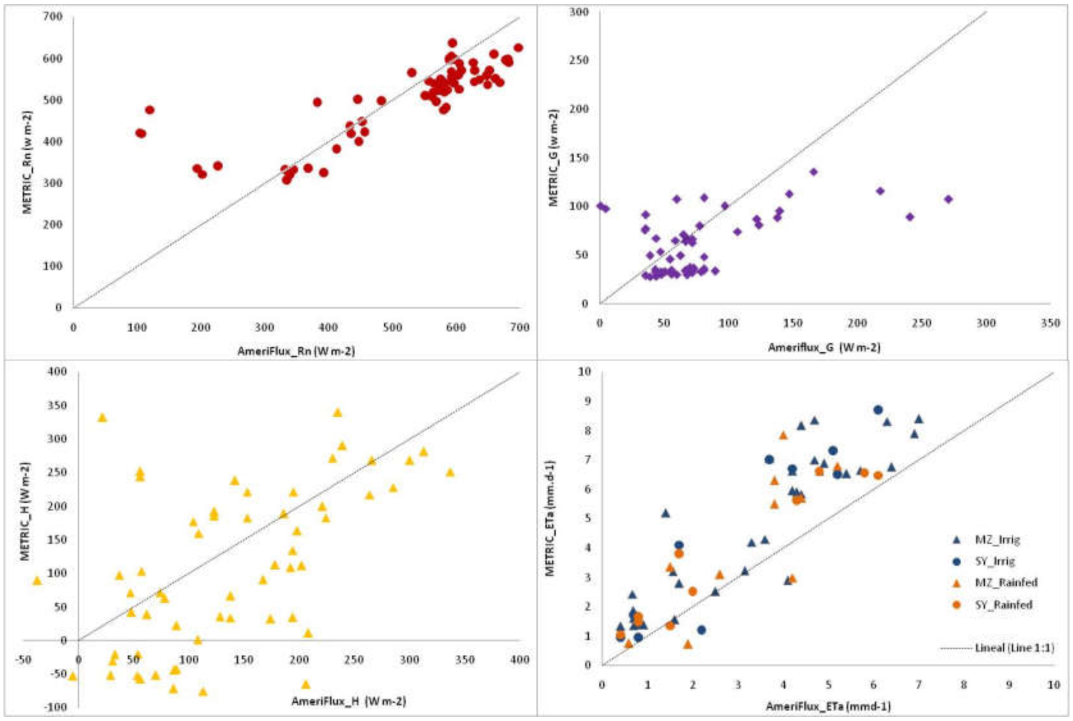

Figure 2. Comparison between predicted and measurement values of each components of energy balance (Rn, G, H and ET) at times overpass Landsat scene during four years of study (2004, 2007, 2010 and 2013).

Figure 3 displays the comparison between estimated and measurement values of ETa using two reference evapotranspiration: alfalfa reference ET (ETr), and grassland reference ET (ETo). Higher errors were observed using ETr than ETo, RMSE of 1.66 and 0.97 mm d^{-1},and Bias of 1.2 and 0.4mm $d^{-1}$with ETr and ETo as a reference evapotranspiration respectively. Slope of lineal regression was 1.146 vs. 0.969 and R^2 of 0.8 vs. 0.82 for ETr and ETo respectively.

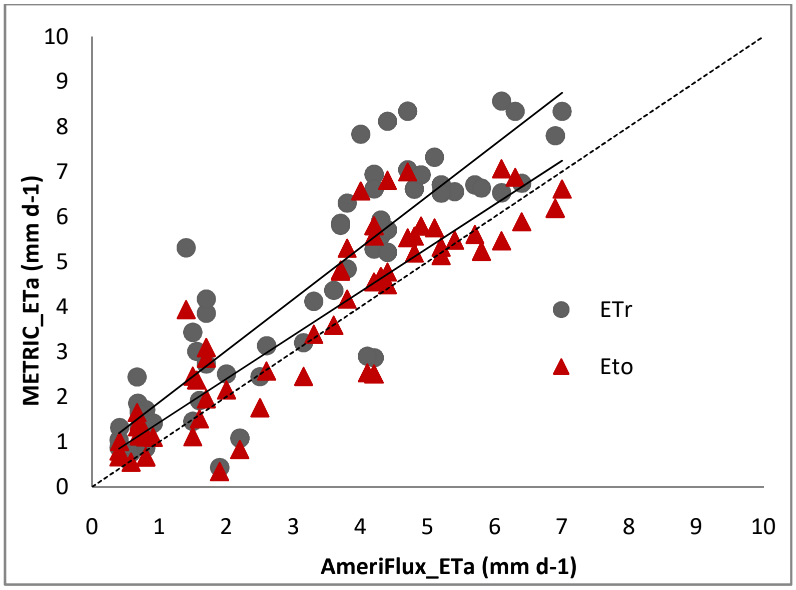

Figure 3. Comparison between measurement and predicted values of actual ET using two reference evapotranspiration: alfalfa reference ET (ETr), and grassland reference ET (ETo).

4. Conclusion

Net radiation and soil heat were acceptably estimated by the model, however sensible and latent heat fluxes predicted by METRIC showed large errors. METRIC overestimated actual ET with an average bias of 1.2 and 0.4mm d^{-1}, when ETr and ETo were used as reference evapotranspiration respectively. Results may be due to poor closure of energy balance for eddy covariance data, or errors in reference ET used in the model of both crops (soybean and maize). These results suggest that would be necessary study which reference ET is more appropriate to use within METRIC depending on the climatic zone.

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