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COMPARISON OF SAFER AND METRIC-BASED ACTUAL EVAPOTRANSPIRATION MODELS IN A SUBTROPICAL AREA OF BRAZIL

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1 ABSTRACT

Remote sensing algorithms are well known to estimate surface energy fluxes in regional to global scales with low cost. The remote sensing approach has an advantage of estimating evapotranspiration (ET) on larger spatiotemporal scales when compared with traditional methods. This study compared the result of ET estimates from the “Simple Algorithm for Evapotranspiration Retrieving” (SAFER) and “Mapping Evapotranspiration at high Resolution with Internal Calibration” (METRIC) models on varied land uses of a subtropical area located in Southeast Brazil by using a image from the sensor OLI of LANDSAT-8. The results showed similarity of ET estimate from both models, although slight deviation especially at high ET values. It happened due differences as the need of anchor pixel in METRIC, which requires two points with extrem thermohydrological conditions in the same area. Minimum ground data requirement is the major advantage of the METRIC over the SAFER model. The maximum value, the sum and ET range by METRIC was higher than SAFER. This study has considered both models feasible for estimation of ET from satellite data in the study area.

Keywords: remote sensing, modelling, superficial temperature, Landsat-8, agriwater.

SILVA, C. O. F.; MANZIONE, R. L.; ALBUQUERQUE FILHO, J. L. COMPARAÇÃO DE MODELOS DE EVAPOTRANSPIRAÇÃO REAL SAFER E METRIC EM UMA ÁREA SUBTROPICAL DO BRASIL

2 RESUMO

Algoritmos de sensoriamento remoto são conhecidos por estimar fluxos de energia de superfície em escalas regionais a globais com baixo custo. A abordagem de sensoriamento remoto tem a vantagem de estimar a evapotranspiração (ET) em escalas espaço-temporais maiores que os métodos tradicionais. Este estudo compara o resultado da estimativa de ET do “Simple Algorithm for Evapotranspiration Retrieving” (SAFER) e “Mapping Evapotranspiration at high Resolution with Internal Calibration” (METRIC) em variados usos da terra de uma área subtropical localizada no Sudeste do Brasil usando uma imagem do sensor OLI do satélite LANDSAT-8. Os resultados mostraram similaridade da estimativa da ET em ambos os

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modelos, embora houvesse desvio, especialmente em altos valores de ET. Isto é devido a diferenças como a necessidade de âncora de pixel no modelo METRIC, que necessita de dois pontos com condições termohidrológicas extremas em uma mesma área. A exigência mínima de dados terrestres é a principal vantagem do METRIC sobre o modelo SAFER. Esse estudo considerou ambos os modelos viáveis para a estimativa de ET a partir de dados de satélite na área de estudo. Neste estudo, o valor máximo, a soma e a variação do ET pelo METRIC foram maiores que o do SAFER.

Palavras-chave: sensoriamento remoto, modelagem, temperatura de superfície, Landsat-8, agriwater.

3 INTRODUÇÃO

During the last decades, there has been increasing need for the accurate estimation of plant water requirement in agricultural sector where large volume of water is consumed. Usually the amount of water consumed by plant is considered as water evaporated from the soil and transpirated by plant. Traditionally evapotranspiration (ET) is estimated from point-based ET models such as Penman-Monteith, Priestly-Taylor, Hargreaves, Blaney–Criddle and crop coefficient approach (HARGREAVES, ALLEN, 2003). However, estimation of spatial distribution of ET over the large area is restricted due to wide-spread distribution of weather stations. On the other hand, crops have different crop coefficient in different stage, therefore, estimation of crop coefficient and crop stages because of large crops population in the nature is difficult (ALLEN et al., 2005a, TEIXEIRA et al., 2014, SILVA, MANZIONE, TEIXEIRA et al., 2019).

Satellite-based estimation of evapotranspiration (ET) have been reported to be essential for spatially evaluation of plant water requirement and water use regulation, particularly in the area with abundant water resources. Therefore, several satellite-based ET models have been developed and evaluated in different climatic conditions during the last couple of years.

In this manner, this study compares the results of two remotely-sensed evapotranspiration algorithms (SAFER and METRIC) in a subtropical area located in Southeast Brazil.

4 MATERIAL AND METHODS

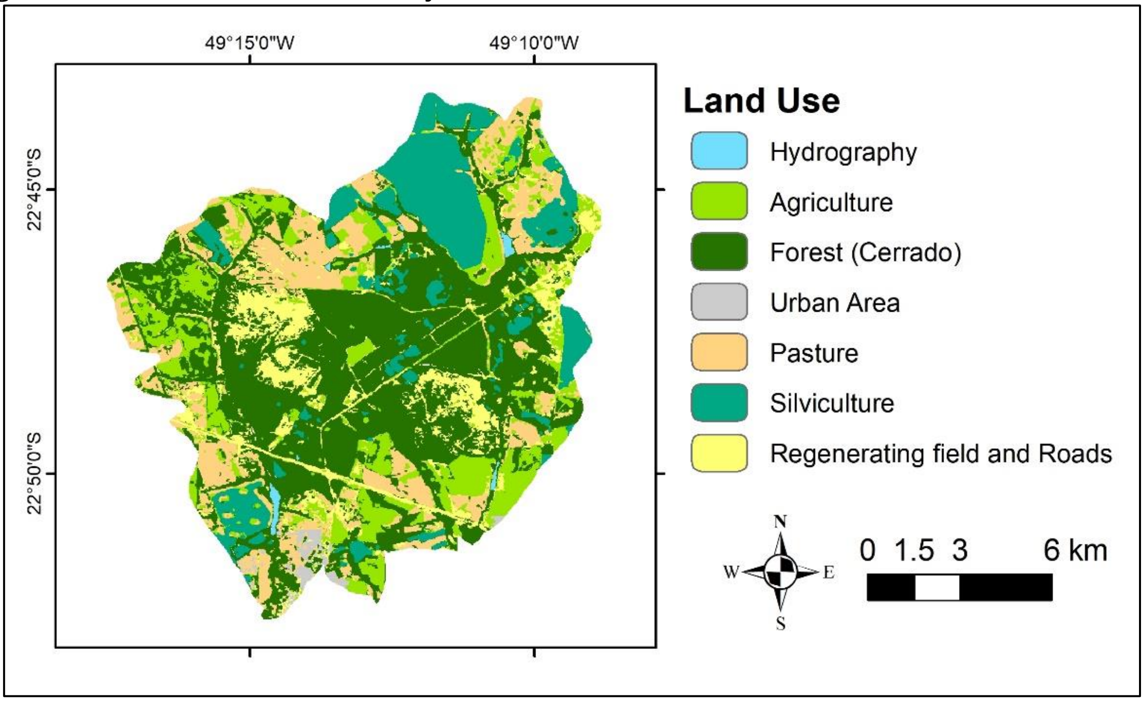
The study area, shown in Figure 1, belongs to the Rio Pardo hydrographic unit, part of the Paranapanema river basin, Water Resources Management Unit 17, Middle Paranapanema (UGRHI 17 - MP). The site is bounded to the east by the Capão Rico River and to the west by the Capivari River.

The land use of the study area of this research (based on DOY 75/2017), which is presented in Fig. 1, are variated: nature vegetation (Cerrado biome) (67 km²), silviculture (Eucalyptus) (22 km²), sugarcane crops (25 km²), urban area (2 km²), regenerating fields (5 km²), roads (0.4 km²) and pasture (40 km²) (SILVA, MANZIONE, ALBUQUERQUE FILHO, 2019).

The northern region of the study area is largely occupied by silviculture. The western region is occupied by agriculture (sugarcane). In the southern region there is occurrence of urban area and the pasture and forest areas occur in the central and eastern region of the study area (SILVA, MANZIONE and ALBUQUERQUE FILHO et al., 2018).

The agrometeorological station within this area have a reference surface where albedo is 0.23 and the LAI 2.88 (MANZIONE, 2019).

Figure 1. Basic land use of the study area



Source: Silva, Manzione, Albuquerque Filho (2019)

The METRIC model (Mapping Evapotranspiration at high Resolution with Internalized Calibration) is a satellite-based image-processing model for calculating evapotranspiration (ET) as a residual of the surface energy balance. METRIC was developed by the University of Idaho (ALLEN, TASUMI, TRESSA et al., 2005a, 2007a, 2007b) for application with Landsat satellite imagery to maximize ET product spatial resolution (30 m). METRIC estimates ET_A as the residual of the surface energy balance (ALLEN et al., 2007b) according to Equation 1.

$$\lambda E = R_n - G - H \quad (1)$$

Where λE is the latent heat flux, R_n is the net radiation, H is the sensible heat flux, and G is the soil heat flux. The ET_A is calculated by dividing the latent heat flux by the latent heat of vaporization of water. Details for the estimation of each component of the surface energy balance and internal calibration of biases can be found in Allen et al. (2007b, 2011).

At the time of satellite-overpass, high ET ("cold pixel" or ET_{cold}) and negligible ET ("hot pixel" or ET_{hot}) pixels were selected for internal calibration (ALLEN et al., 2007b). This procedure is based on information provided in the satellite images, and should not be equated to the calibration of crop models using observed field data. Details for the estimation of each component of the surface energy balance and internal calibration of biases can be found in Allen et al. (2007b, 2011).

Short-grass standardized Penman–Monteith reference crop evapotranspiration (ET_o) (ASCE-EWRI, 2005) were used. Adopting the approach by Chávez et al. (2008, 2012), a crop coefficient K, and the METRIC "cold pixel" (ET_{cold}) to determine ET_oF, the ratio of ETcold to a calculated crop ET based on weather data, based on Equation 2.

$$ET_oF = ET_{cold}\,\frac{K}{ET_o} \quad (2)$$

Although K values are suggested in the METRIC literature a K value of 0.85 was obtained, which is adequate for dry conditions (CONRAD et al., 2007; LIAQAT and CHOI, 2015). Values of ET_oF for satellite pass days were calculated for all pixels in the image by scaling ET_oF of the cold pixel by ET/ET_{cold} based on values for satellite pass days, daily ET_oF values for all pixels were determined using cubic spline interpolation and daily ET_o determined from weather data, thus allowing the calculation of daily ET_A of each cell for the day multiplied by daily ET_o). METRIC was performed using the R package “water”.

$$ET_A = ET_oF\ ET_o \quad (3)$$

In the other hand, the “Simple Algorithm for Evapotranspiration Retrieving” (SAFER) was used for modeling the instantaneous values of the ratio of actual (ET_A) to the reference (ET_o) evapotranspiration, which was then multiplied by ET_o from the agrometeorological stations for estimating the daily ET large-scale values, based on Equation 4.

$$\frac{ET_A}{ET_o} = \exp\left[a + b\left(\frac{T_S}{\alpha_0 \cdot NDVI}\right)\right] \quad (4)$$

Where α_0 is the surface albedo (dimensionless), NDVI is the Normalized Difference Vegetation Index (dimensionless), T_S is the surface temperature (°C), and a and b are respectively 1.8 and -0.0008 (TEIXEIRA et al., 2014; SILVA et al., 2019). Surface temperature was modeled from the residue of the Stefan-Boltzmann equation without the use of thermal bands (SILVA et al., 2019).

The complete formulation of SAFER and its practical application with the R package "agriwater" is described by Silva et al. (2019). An essential difference between the two models is that METRIC bases evapotranspiration modeling on the energy balance equation (Eq. 1) while SAFER is based on three satellite image dependent parameters: NDVI, surface albedo and temperature of surface (Eq. 4). A Landsat-8 image from 26th November 2016 was used to apply both methods in the study area, using $ET_o = 4.3$ mm.

Model results were compared using Zonal Statistics, in R, using land use (Figure 1) to obtain averages per land use. Scatterplots were also made to evaluate the difference between the models. Because there were no measured ET_A values, it was not possible to apply metrics such as RMSE.

5 RESULTS AND DISCUSSION

The comparison of the surface temperature and actual evapotranspiration retrivied from METRIC and SAFER is shown in Figure 2. Average values of land surface temperature and actual evapotranspiration for the main land uses of the study area were presented in Table 1. Silviculture and forest presented surface temperatures around 2 K smaller than pasture and sugarcane in METRIC and 7 K in SAFER. SAFER is more sensitive to surface temperature than METRIC, so ET_A values using SAFER were higher. Silva et al. (2019) have already suggested that surface temperature modeling without thermal bands needs to be better evaluated in future work.

Figure 2. Spatial distribution of the daily values for surface temperature and actual evapotranspiration from the mixed agroecosystems in Águas de Santa Bárbara in 26th November 2016 with a Landsat-8 digital image

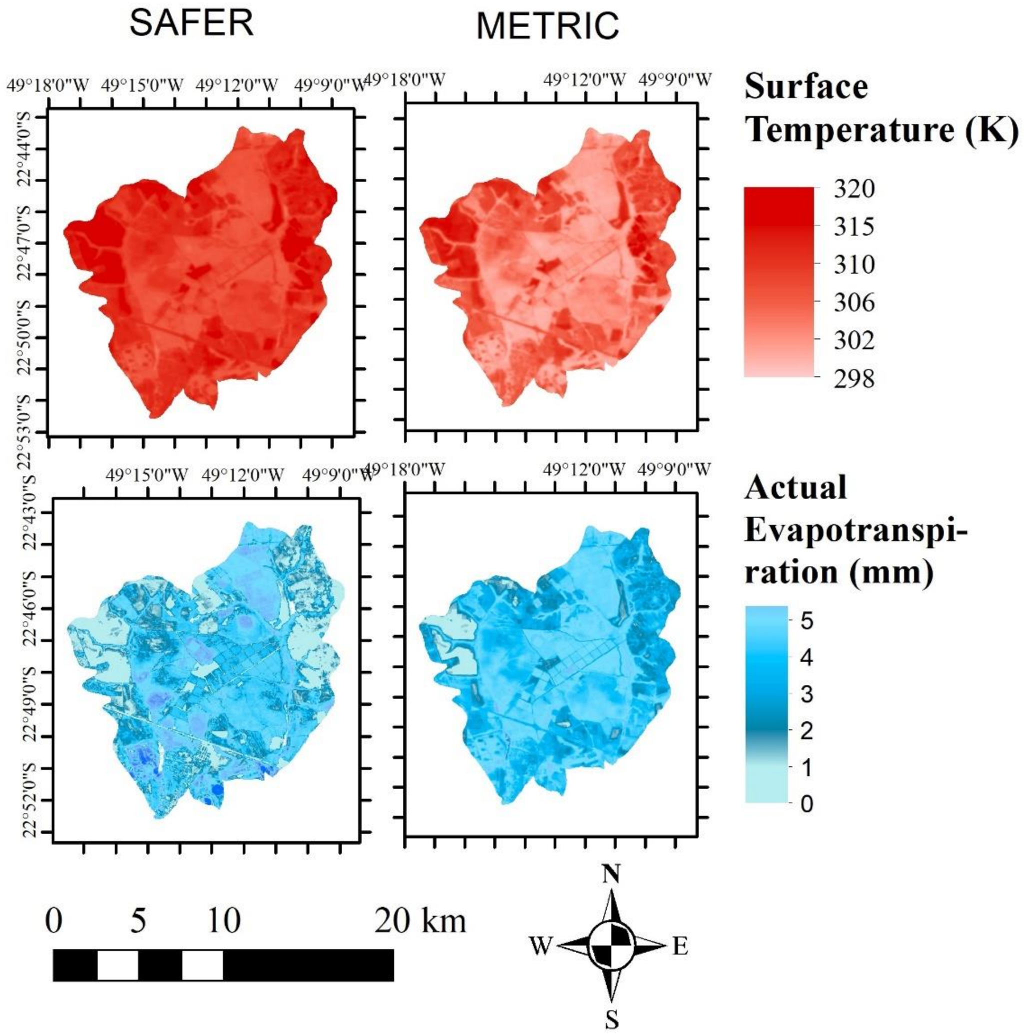


Table 1. Average values of land surface temperature and actual evapotranspiration for the main land uses of the study area in Águas de Santa Bárbara in 26th November 2016 with a Landsat-8 digital image.

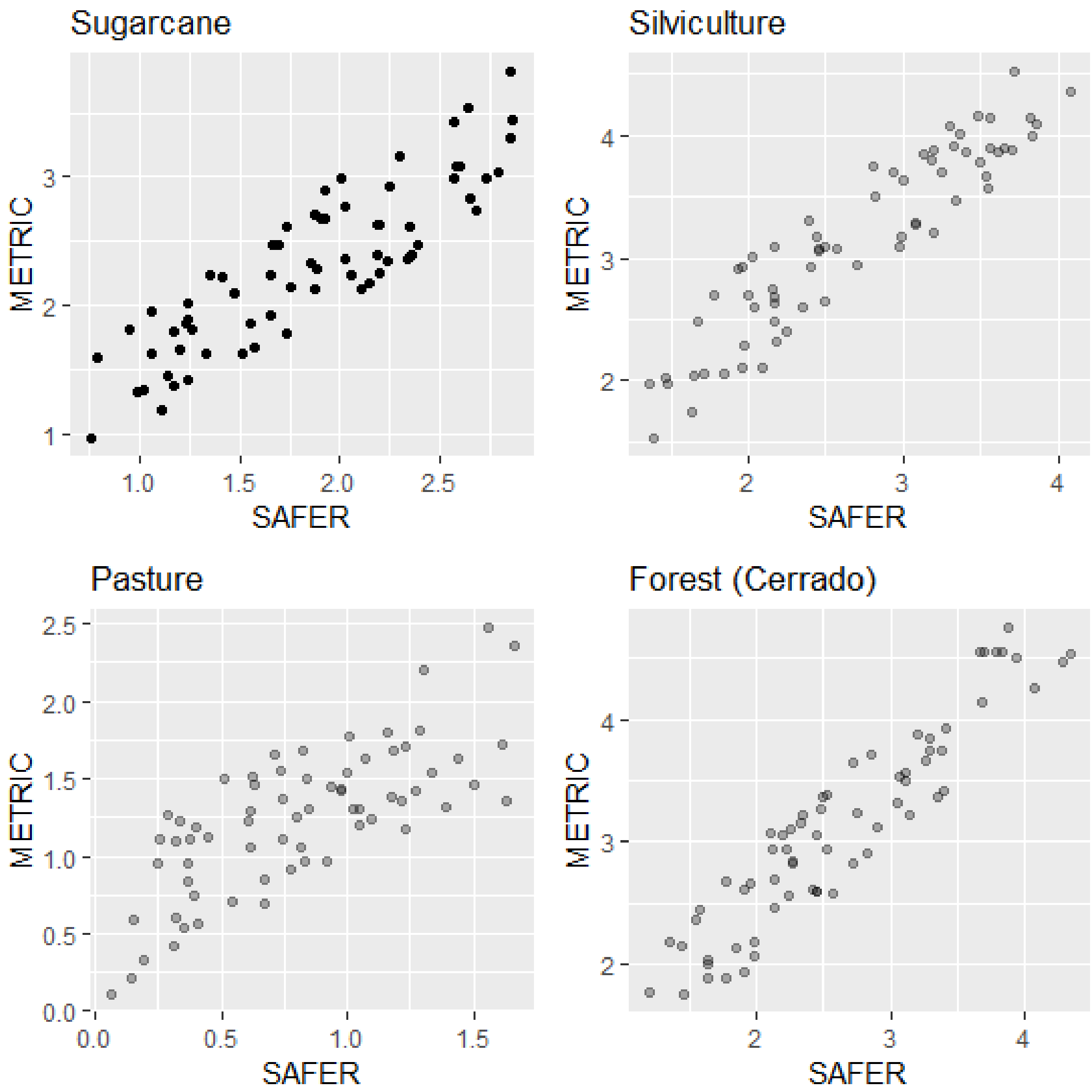
Parameter	Method	Sugarcane	Pasture	Silviculture	Forest
Land surface temperature (K)	SAFER	315 ± 0.7	310 ± 0.6	299 ± 0.7	299 ± 0.9
	METRIC	309 ± 0.7	308 ± 0.5	304 ± 0.8	306 ± 0.4
Actual evapotranspiration ($mm\ day^{-1}$)	SAFER	1.8 ± 0.9	1.2 ± 0.3	3.0 ± 0.8	3.6 ± 0.7
	METRIC	2.3 ± 0.8	1.5 ± 0.2	3.9 ± 0.7	3.8 ± 0.9

The results showed similarity of ET_A estimate from models, although high deviation especially at high ET_A values was observed. This is due to differences as the need of anchor pixel in METRIC and the assumptions of SAFER in extrapolating air temperature to land surface temperate on a daily basis. However, minimum ground data requirement is the major advantage of the METRIC over the SAFER model.

Although, SAFER requires high quality weather data from the ground station located inside the study area, it takes into account daily variability of climatic parameter. Samples of 68 pixels from each main land uses were used to generate the scatterplot of Figure 3, where some darker points occur because of overlapping points. Forest (Cerrado) and silviculture showed similar ET_A values while pasture reached the lowest values.

The main difficulty for the use of METRIC is the requirement of extreme thermohydrological conditions, so-called "hot pixel" and "cold pixel", being necessary to approximate these conditions for exposed soil and river areas, respectively. Silva, Silva, Santos (2019) and Foolad et al. (2019) developed automation of hot pixel and cold pixel selection for the SEBAL and METRIC models, respectively.

Figure 3. Scatterplot comparing actual evapotranspiration values from samples of 68 pixels from each main land use of the study area.



6 CONCLUSIONS

The study has considered both models feasible for estimation of ET_A from satellite data in the study area. In this study, the maximum value, the sum and ET_A range by METRIC was higher than SAFER because the surface temperature retrieved by SAFER was always higher than that of METRIC, generating lower ET_A values. In future studies, more days of the year with different climatic conditions need to be evaluated to compare the behavior of the models throughout the hydrological year.

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