IV INOVAGRI INTERNATIONAL MEETING
XXVI CONIRD - CONGRESSO NACIONAL DE IRRIGAÇÃO E DRENAGEM
III SBS - SIMPÓSIO BRASILEIRO DE SALINIDADE

EVALUATION OF DIFFERENT ALGORITHMS TO ESTIMATE THE EVAPOTRANSPIRATION IN CROP AREA WITH HUMID SUBTROPICAL CLIMATE

P. F. C. Monteiro[1], T. V. dos Santos[2], D. C. Fontana[3], R. O. C. Monteiro[4], J. M. A. Espinoza[5], M. G. Albuquerque[6]

ABSTRACT: A field experiment was carried out to implement and evaluate the adequacy of the Mapping Evapotranspiration at High Resolution with Internalized Calibration (METRIC) and One-Source Energy Balance (OSEB) algorithm to estimate the evapotranspiration over soybean field with subtropical climate conditions located in Vacaria, Rio Grande do Sul, South Region of Brazil. For this study, Terra/MODIS images were aquired from November 2013 to March 2014. The METRIC and OSEB were the algorithms used to analyze and to compare the partition of net radiation (Rn), sensible heat flux (H), soil heat flux (G) and latente heat flux (LE) observed on flux station and estimated from the MODIS images. Meteorological variables and surface energy balance components were measured at the time of the Terra/MODIS overpass. The performance of the algorithms were evaluated using measurements of H and LE obtained from a bowen ratio system. The OSEB model showed better results compared with METRIC model to estimate the energy fluxes and evapotranspiration over a soybean crop area using Terra MODIS remote sensing datasets.

KEYWORDS: remote sensing, Landsat images, energy balance

AVALIAÇÃO DE DIFERENTES ALGORITMOS NA ESTIMATIVA DA EVAPOTRANSPIRAÇÃO EM ÁREAS DE CULTIVO EM REGIÕES DE CLIMA SUBTROPICAL ÚMIDO

RESUMO: Este estudo foi conduzido a campo para implementar e avaliar a adequação dos algoritmos *Mapping Evapotranspiration at High Resolution with Internalized Calibration*

[1] Doutora, Pesquisadora do Departamento de Diagnóstico e Pesquisa Agropecuária da Secretaria de Agricultura, Vacaria – Rio Grande do Sul. E-mail: priscylla-monteiro@fepagro.rs.gov.br
[2] Doutorando, University of Minnesota, Minneapolis – Minnesota. E-mail: thiagoveloso@gmail.com
[3] Doutora, Professora do Departamento de Agrometeorologia da UFRGS, Porto Alegre – Rio Grande do Sul. E-mail: dfontana@ufrgs.br
[4] Doutor, Professor do IFRS, Bento Gonçalves – Rio Grande do Sul. E-mail: rodrigo.monteiro@bento.ifrs.edu.br
[5] Doutor, Professor do IFRS, Rio Grande – Rio Grande do Sul. E-mail: jean.espinoza@riogrande.ifrs.edu.br
[6] Doutor, Professor do IFRS, Rio Grande – Rio Grande do Sul. E-mail: miguel.albuquerque@riogrande.ifrs.edu.br

(METRIC) e *One-Source Energy Balance* (OSEB) na estimativa da evapotranspiração de áreas de cultivo de soja nas condições de clima subtropical úmido localizada em Vacaria, Rio Grande do Sul, Brasil. Para este estudo as imagens Terra/MODIS obtidas foram de novembro de 2013 a março de 2014. O METRIC e OSEB foram os algoritmos utilizados para analisar e comparar o saldo de radiação (Rn), fluxo de calor sensível (H), fluxo de calor no solo (G) e fluxo de calor latente (LE) observados na estação de fluxo e estimados pelas imagens MODIS. As variáveis meteorológicas e os componentes do balanço de energia foram medidos no momento da passagem do satélite Terra/MODIS. A performance dos algoritmos foi avaliada utilizando as medidas de H e LE obtidas pela razão de bowen. O modelo OSEB mostrou melhores resultados, quando comparado com o modelo METRIC, na estimativa dos fluxos de energia e evapotranspiração da cultura de soja utilizando os dados do satélite Terra/MODIS.

PALAVRAS-CHAVE: sensoriamento remoto, imagens Landsat, balanço de energia

INTRODUCTION

Agriculture is a base of economy of Rio Grande do Sul (RS) state and soybean crop is the largest cultivated area. In the 2010/2011 the soybean harvest was 4,085 million hectares with 11,621 million tons and yield mean of 2,845 kg ha^{-1} (CONAB, 2012). The soybean cultivated area is more than 50% of RS cultivated area and more than 60% of the total grain production of the state (CONAB, 2012).

Considering that practically all grains (except irrigated rice) produced in the state come from dry land fields, production and productivity presents high inter-annual variability, determined mainly by rainfall variability (Berlato and Fontana, 1999). ET is traditionally calculated as a difference of water-balance terms, whilst it is measured by instruments such as lysimeters or eddy-correlation (EC) systems which uses high frequency Atmospheric measurements. However, such methods provide values of ET at specific sites and not at a regional or larger scale (Neves et al., 2007). Because the high costs to install flux station systems and economic and human resources scarce, methods have therefore been developed in recent years which provide rapidly available hydrological data over large areas based on remote sensing.

Most of the ET algorithms used to estimate spatially ET crop are based on the land surface energy balance (EB) model. To estimate the EB fluxes a number of algorithms have been developed in the past few decades that include one source models, such as SEBAL (Surface

Energy Balance Algorithm for Land), METRIC (Mapping EvapoTranspiration with Internalized Calibration) and SEBS (Surface Energy Balance System), and multi-source models, such as T-SEB (Two-Source Energy Balance), R-SEB (Aerodynamic Resistance Surface Energy Balance) and SEB-4S (Four-Source Surface Energy Balance). The one-source models treat the vegetation and soil as one "big leaf" with the same temperature and aerodynamic resistance for heat transfer and the same height (Boegh et al., 2002, Wang et al., 2006, Sánchez et al., 2008, Timmermans et al., 2007 e Tang et al., 2013). On the other hand, the multi-source models, in which vegetation and soil are independent of heat fluxes (Sánchez et al., 2008, Cammalleri et al., 2012, Tang et al., 2013).

Although the MODIS sensor has a low spatial resolution the great advantage of this sensor data is the temporal resolution, since they can be used to estimate energy fluxes at regional scales at daily time intervals, which is not possible with another sensor that has less frequent revisits. The high radiometric sensitivity of MODIS's 36 spectral bands associated with geometric and atmospheric corrections can compensate for lower spatial resolution.

Thus, the main objective of this research was to implement and evaluate the adequacy of METRIC (Mapping Evapotranspiration at High Resolution with Internalized Calibration) and OSEB (One-Source Energy Balance) algorithms to estimate the energy fluxes and evapotranspiration over a soybean crop area using Terra MODIS remote sensing datasets.

MATERIAL AND METHODS

1. Study site

The data were collected in dry land soybean field located in Southern Brazil at coordinates 28º24'52,5"S and 50º50'53,8"W between 20 November 2013 and 30 May 2014. The climate is Cfa (Humid subtropical climate) type according to the Koppen classification with average annual rainfall of 1.900 mm. The surface elevation is about 930m above sea level. The soil in the experimental field is classified as Latosol Bruno, with small slope and high levels of clay and aluminum (EMBRAPA, 2006). The land cover types are mainly anual crops but have apple and small fruits (strawberry, blackberry, blueberry). Winter wheat and summer soybean are rotated as the main land covers at the lite station. The annual average temperature is approximately 16,2ºC.

2. Measurements of Energy Balance and Climatic Data

Micrometeorological instruments for measuring the meteorological and flux data were installed at the experimental field in late October 2013. The meteorological data needed for running the two models, METRIC and OSEB, include air temperature and wind speed. These were all measured at approximately 2m above local ground level and recorded as 5 min averages on an electronic datalogger (CR1000, Campbell Sci, Logan, UT, USA). The system measures a net radiation with CNR4 (Kipp & Zonen Inc., Delft, The Netherlands) radiometer at a height of 1.80m, soil heat flux with a single HFP01(Campbell) soil heat flux plate at a soil depth of 0.05m, air temperature and relative humidity with two CS215 (Vaisala) at a height of 1.2m and 2.70m, wind speed and direction with 03002 (RM Young) at a height of 2.10 m, precipitation with TB4 (Campbell) at a height of 2.10 m. One averaging thermocouple probes (108 – Campbell) for measuring soil temperature were installed behind flux plate at depth of 0.05m. Assuming that the measurements of net radiation (Rn) and soil heat flux (G) were representative of the available energy in the soybean field, the fluxes of H and latent heat flux (LE) for remaining data were calculated using the Bowen ratio approach (Eq.1; Eq.2):

$$LE = \frac{(Rn - G)}{(1+\beta)} \qquad (1)$$

where β (=H / LE) is the Bowen ratio (dimensionless)

3. Remote sensing data

The remote sensing data used in this study are from MODIS/Terra products. The Terra satellite launched in December 1999 and view the entire earth surface every 1-2 days. Terra has a 10:30 am equator over-passing time. The MODIS sensor onboard the Terra satellite acquire data in 36 spectral channels with a spatial resolution of 250 m for visible bands, 500 m for near-infrared bands, and 1000 for thermal infrared bands. The data used in this research are from the Land Processes Distributed Active Archive Center (LP DAAC) and include surface reflectance, MOD09GQ and MOD09GA, at 250 m and 500 m spatial resolution and land surface temperature (MOD11A1) at 1000 m of spatial resolution.

The MODIS/Terra overpasses were selected by the absence of cloud cover over the area throughout the day (verified from the global solar radiation data) and the availability of MODIS products with adequate quality. According to that criteria and by ground based measurements for calibration, the number of available clear-sky MODIS/Terra overpass was 6 from November 2013 to May 2014.

4. Evapotranspiration models

In energy balance (EB) componentes, Rn and G are easily estimated from remote sensing images (Sánchez et al., 2008). On the other hand the estimation of the turbulent fluxes in more complex. In most of EB models LE is obteined as the residual term of the energy balance equation (Eq.2).

$$LE = Rn - G - H \qquad (2)$$

where, Rn is the net radiation resulting from the budget of short and long wave incoming and emitted radiation respectively, LE is the latent heat flux from evapotranspiration, G is the soil heat flux, and H is the sensible heat flux (all in W m^{-2} units).

The net radiation is the first term of the energy balance equation and is calculated as (Eq.3):

$$R_n = (1 - \alpha)\, R_s + \varepsilon_a\, \sigma\, T_a^4 - \varepsilon_s\, \sigma\, T_s^4 \qquad (3)$$

where α is surface albedo, R_s is incoming short wave radiation (W m^{-2}) measured with piranometers or calculated using the Angstrom formula based on the solar constant, location and time of the year (Allen et al. 1998) or by using the solar constant, the cosine of the solar incidence angle, the inverse squared relative earth–sun distance, and atmospheric transmissivity based on the area of interest (image) ground elevation respect to mean sea level (Allen et al. 2007), σ is the Stefan–Boltzmann constant (5.67 E-08 W m^{-2} K^{-4}), *e* is emissivity and T temperature (K) with subscripts ‘‘a’’ and ‘‘s’’ for air and surface, respectively. T*s* is the remotely sensed radiometric surface temperature which is obtained after correcting the sensor brightness temperature imagery for atmospheric effects and for surface emissivity considering, for example, procedures by Brunsell and Gillies (2002). The surface emissivity correction is performed assuming typical bare soil and fully vegetated surface emissivities of 0.93 and 0.98, respectively, and the fractional vegetation cover from the scaled normalized difference vegetation index (NDVI).

The α, Ts and ε_s parameters were determined from the MODIS images while the other components from the experimental data were obteined at the wheather station (Rivas and Caselles, 2004; Sobrino et al., 2005).

The main difference between the two algoritms (METRIC and OSEB) is how the sensible heat flux (H) is calculated. Both models estimate H from a temperature differential and aerodynamic resistance (Eq.4).

$$H = \rho Cp \frac{dT}{ra} \qquad (4)$$

where ρ is the air density (1.15 kg m^{-3}), *cp* (1004 J Kg^{-1} K^{-1}) is the specific heat of humid air at constant pressure, *dT* (for METRIC) is the differential temperature between two levels on the surface and *ra* is the aerodynamic resistance to heat transport (s m^{-1}). For OSEB model, the differential temperature *dT* is the difference between surface, get from sattelite images, and air temperature, usually obteined from meteorological station at 2m above the surface (Wang et al., 2006) and *ra* is obteined from wind speed (s m^{-1}) according Allen at al. (1998).

For METRIC model, the differential temperature and aerodynamic resistance are obteined from iterative calculation procedure. A full description of the METRIC can be found in Allen et al. (2002, 2005, 2007).

Soil heat flux (G), in both models, are estimated as a fracion of Rn (Allen, 1998; Santanello and Friedl, 2003; Boegh et al., 2002; Qi et al., 1994). In the METRIC and OSEB model G is estimated by Equation 6 and 7, respectively.

$$G = \left[\frac{Ts}{\propto}(0.0038 \propto + 0.0074^2)(1 - 0.98NDVI^4)\right] Rn \qquad (5)$$

where Ts = surface temperature (K); α = surface albedo and *Rn* = net radiation (W m^{-2}).

$$G = 0.583\exp(-2.13NDVI)Rn \qquad (6)$$

RESULTS AND DISCUSSION

The estimates of the energy balance components (Rn, H, G and LE) obtained by combining METRIC and OSEB models with Terra/MODIS images were compared with the wheather station measurements (Table 1 and Table 2) that were adjusted for energy balance closure using the Bowen ratio method.

The following three statistical parameters were chosen to measure the strength of the relationship between the simulated and measured results: the root mean square (RMSD), bias and mean absolute percentage difference (MAPD).

Table 1. Energy balance components: net radiation (Rn), sensible heat flux (H), soil heat flux (G) and latente heat flux (LE), measured and estimated using the METRIC model extracted from the Terra/MODIS images in the meteorological station coordinates in Vacaria, Rio Grande do Sul, Brazil

Flux	**Day**	**Observed Average (W m^{-2})**	**Simulated METRIC (W m^{-2})**	**Bias (W m^{-2})**	**% Rn**	**RMSD (W m^{-2})**	**MAPD (%)**
Rn	18 Nov 2013	838.46	691.87	-146.59	-	109.5	5.64
	20 Dez 2013	818.41	685.86	-132.55	-		

	21 Jan 2014	740.27	646.03	-94.24	-		
	26 Mar 2014	519.63	514.93	-4.7	-		
G	18 Nov 2013	50.46	119.03	68.57	17	58.2	16.3
	20 Dez 2013	63.46	128.82	65.36	18		
	21 Jan 2014	52.06	113.67	61.61	17		
	26 Mar 2014	5.61	33.59	27.98	6		
H	18 Nov 2013	236.42	331.16	94.74	47	105.9	7.8
	20 Dez 2013	440.22	387.19	-53.03	56		
	21 Jan 2014	259.16	374.83	115.67	58		
	26 Mar 2014	236.42	376.92	140.5	73		
LE	18 Nov 2013	551.58	241.68	383.67	34	234.9	36.3
	20 Dez 2013	314.73	169.85	269.81	24		
	21 Jan 2014	429.05	157.53	388.08	24		
	26 Mar 2014	277.6	104.42	266.85	20		

Table 2. Energy balance components: net radiation (Rn), sensible heat flux (H), soil heat flux (G) and latente heat flux (LE), measured and estimated using the OSEB model extracted from the Terra/MODIS images in the meteorological station coordinates in Vacaria, Rio Grande do Sul, Brazil

Flux	**Day**	**Observed Average ($W m^{-2}$)**	**Simulated OSEB ($W m^{-2}$)**	**Bias ($W m^{-2}$)**	**% Rn**	**RMSD ($W m^{-2}$)**	**MAPD (%)**
Rn	18 Nov 2013	838.46	791.87	-46.59	-	36	1.5
	20 Dez 2013	818.41	785.86	-32.55	-		
	21 Jan 2014	740.27	696.03	-44.24	-		
	26 Mar 2014	519.63	514.93	-4.7	-		
G	18 Nov 2013	50.46	137.03	86.57	17	49.8	17.3
	20 Dez 2013	63.46	88.77	25.31	11		
	21 Jan 2014	52.06	83.84	31.78	12		
	26 Mar 2014	5.61	33.59	27.98	6		
H	18 Nov 2013	236.42	271.17	34.75	34	27.7	3.5
	20 Dez 2013	440.22	427.28	-12.94	54		
	21 Jan 2014	259.16	224.11	-35.05	32		
	26 Mar 2014	236.42	214.49	-21.93	41		
LE	18 Nov 2013	551.58	383.67	-167.91	48	89.4	11.2
	20 Dez 2013	314.73	269.81	-44.92	34		
	21 Jan 2014	429.05	388.08	-40.97	55		
	26 Mar 2014	277.6	266.85	-10.75	51		

The results indicate that, in general, all four componentes of the energy balance equation desagree the weather station. The both models underestimated the net radiation (Rn) and the latente heat flux (LE) for all days (Tabela 1). The Rn values are adequate with lower value in

March 2014 because the soybean began to transition into its senescence stage. The Rn is the easiest parameter estimated and according to Timmermans et al. (2007) the erros was around 31 Wm^{-2} using OSEB model in maize crop area.

The soil heat flux (G) agree that is usually responsible for lower energy comsumption and showed lower than 18% for both models all days. The most dates, for OSEB model, LE is higher than H, consistente with the pattern observed in the mean values. At the same time on 20 December 2013, at the begining of the summer crops, the H was higher than LE.

Table 3. Evapotranspiration estimated using the METRIC and OSEB models extracted from the Terra/MODIS images in the meteorological station coordinates in Vacaria, Rio Grande do Sul, Brazil

Date	ET ($mm\ dia^{-1}$)	
	METRIC	OSEB
18 Nov 2013	3.81	4.81
20 Dez 2013	2.29	3.17
21 Jan 2014	5.57	6.21
26 Mar 2014	3.49	3.89

CONCLUSION

The OSEB model showed better results compared with METRIC model to estimate the energy fluxes and evapotranspiration over a soybean crop area using Terra MODIS remote sensing datasets.

The METRIC and OSEB models showed potential to map the spatial and temporal energy balance components and evapotranspiration variability, showing sensitivity to different crop development stages.

ACKNOWLEDGMENT

To CNPq (Process 482727/2012-8) by financial support;

REFERENCES

Allen, R.G.; Pereira, L.S.; Raes, D; Smith, M. Crop Evapotranspiration: Guidelines for computing crop water requirements. FAO. 1998. 300p. (FAO Irrigation and Drainage Paper, 56).

Allen, R.G.; Tasumi, M.; Trezza, R.; Waters, R.; Bastiaanssen, WG.M. Surface Energy Balance Algorithm for Land (SEBAL)—Advanced Training and User's Manual; University of Idaho: Kimberly, ID, USA, 2002; 98 p.

Allen, R.G.; Clemmens, A.J.; Burt, C.M.; Solomon, K.; O'Halloran, T. Prediction accuracy for projectwide evapotranspiration using crop coefficients and reference evapotranspiration. Journal of Irrigation Drainage Engineering, v. 131, p. 24-36, 2005.

Allen RG, Tasumi M, Trezza R (2007) Satellite-based energy balance for mapping evapotranspiration with internalized calibration (METRIC)-model. ASCE J Irrig Drain Eng 133(4):380–394

Berlato, M.A.; Fontana, D.C. Variabilidade interanual da precipitação e variabilidade dos rendimentos da soja no Estado do Rio Grande do Sul. Revista Brasileira de Agrometeorologia, v. 7, p. 119-125, 1999.

Boegh, E.; Soegaard, H.; Thomsen, A. Evaluating evapotranspiration rates and surface conditions using landsat tm to estimate atmospheric resistance and surface resistance. Remote Sens. Environ. 2002, 79, 329–343. http://dx.doi.org/10.1016/S0034-4257(01)00283-8

Brunsell, N.A., Gillies, R.R., 2002. Incorporation of surface emissivity into a thermal atmospheric correction. Photogrammetr. Eng. Remote Sens. 68 (12), 1263–1296

Cammalleri, C., Anderson, M. C., Ciraolo, G., D'Urso, G., Kustas, W. P., La Loggia, G., and Minacapilli, M.: Applications of a remote sensing-based two-source energy balance algorithm for mapping surface fluxes without in situ air temperature observations, Remote Sens. Environ., 124, 502–515, doi:10.1016/j.rse.2012.06.009, 2012.

Companhia Nacional de Abastecimento. Comparativo de área, produção e produtividade safra 2011/2012. Disponível em: http://www.conab.gov.br. Acesso em: 10 maio 2012.

EMBRAPA (Empresa Brasileira de Pesquisa Agropecuária). Centro Nacional de Pesquisa de Solos. Sistema Brasileiro de Classificação de Solos. 2. ed. Rio de Janeiro: Embrapa Solos, 2006. 306p.

Neves, B.V.B.; Versani, B.R.; Rodrigues, P.C.H. Geoprocessamento como ferramenta no estudo de correlação entre a dinâmica da cobertura vegetal e a evapotranspiração. Revista Brasileira de Recursos Hídricos, v.12, p.87-102, 2007.

Qi, J.; Chehbouni, A.; Huete, A.R.; Kerr, Y.H.; and Sorooshian, S. (1994). A modified soil adjusted vegetation index (MSAVI). Remote Sensing Environment, 48, 119-126. http://dx.doi.org/10.1016/0034-4257(94)90134-1

Rivas, R.; Caselles, V. A simplified equation to estimate spatial reference evaporation from remote sensing –based surface temperature and local meteorological data. Remote Sensing of Environment. 2004, 93, 68-76. http://dx.doi.org/10.1016/j.rse.2004.06.021

Sanchez, J.M.; Kustas, W.P.; Caselles, V.; Anderson, M. Modelling surface energy fluxes over maize using a two-source patch model and radiometric soil and canopy temperature observations. Remote Sensing Environmental. 2008, 112, 1130–1143.

Santanello, J.A.; and Friedl, M.A. Diurnal covariation in soil heat flux and net radiation. Journal of Applied Meteorology. 2003, 42, 851-862.

http://dx.doi.org/10.1175/1520-0450(2003)042<0851:DCISHF>2.0.CO;2

Sobrino, J.; Gomez, M.; Jiménez Muñoz, J.C.; Olioso, A.; and Chehbouni, G. A simple algorithm to estimate evapotranspiration from DAIS data: Application to the DAISEX campaigns. Journal of Hydrology. 2005, 315, 117-125. http://dx.doi.org/10.1016/j.jhydrol.2005.03.027

Tang, R.; Li, Z.L.; Jia, Y.; Li, C.; Chen, K.S.; Sun, X.; and Lou, J. Evaluating one- and two-source energy balance models in estimating surface evapotranspiration from Landsat-derived surface temperature and field measurements. International 404 Journal of Remote Sensing. 2013, 34, 3299-3313. http://dx.doi.org/10.1080/01431161.2012.716529

Timmermans,W.J.; Kustas,W.P.; Anderson, M.C.; French, A.N. An intercomparison of the Surface Energy Balance Algorithm for Land (SEBAL) and the Two-source Energy Balance (TSEB) modeling schemes. Remote Sensing of Environmental. 2007, 108, 369–384.

Wang, K.C.; Li, Z.Q.; Cribb, M. Estimation of evaporative fraction from a combination of day and night land surface temperatures and NDVI: A new method to determine the priestley-taylor parameter. Remote Sens. Environ. 2006, 102, 293–305.