# OSEB AND METRIC MODELS FOR DETERMINING A TIME SERIES OF THE ENERGY BALANCE

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**ABSTRACT**: Despite the relevance of the knowledge on the spatial and temporal patterns of the energy balance components (EB) to the agronomic sciences, this information is not yet available. The difficulty partially arises from the uncertainties of the proposed models but also occurs due to restrictive access to the necessary data. A great number of the models are based on the combined use of surface data and satellite images, which can sometimes make the compatibility between databases a complex step of the process. The objective of this work was to analyze the performance of the OSEB (One-Source Energy Balance) and METRIC (Mapping Evapotranspiration with Internalized Calibration) models used in combination with reanalysis data and satellite images, to build a time series of EB components in Southern Brazil. For this, the MODIS products (surface temperature, albedo, vegetation index and leaf area index), ERA-Interim data (air temperature, global solar radiation, and wind speed) and micrometeorological station data (Eddy Covariance) covering a period of three years with periodicity of 8 days were used in the study. The results showed that both EB models and the micrometeorological tower data behaved similarly, with predominance of the LE component in summer and winter, and alternation between these components in the partial coverage period. However, the METRIC model was more coherent with the station data regarding both, the pattern and magnitudes, especially regarding the spatial distribution of latent heat.

**KEYWORDS**: MODIS Products; ERA-Interim; Eddy Covariance.

# MODELOS OSEB E METRIC PARA CONSTRUÇÃO DE SÉRIE TEMPORAL DE BALANÇO DE ENERGIA

**RESUMO**: Apesar da relevância do conhecimento dos padrões de distribuição espaço temporal dos componentes do balanço de energia (BE) no contexto agronômico, esta informação ainda não está disponível. Em parte isto decorre das incertezas dos modelos propostos, mas também

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ocorre devido às restrições de acesso aos dados necessários. Grande parte dos modelos são baseados no uso combinado de imagens de satélite e dados de superfície para obtenção dos componentes de BE. O objetivo deste trabalho foi analisar desempenho dos modelos OSEB *(One*-Source *Energy Balance*) e METRIC (*Mapping Evapotranspiration with Internalized Calibration*) para construção de uma série temporal dos componentes de BE no sul do Brasil, a partir do uso conjugado de dados de reanálise e de imagens de satélite. Foram utilizados produtos MODIS, dados meteorológicos de reanálise ERA-Interim e dados de torre micrometeorológica (*Eddy Covariance*) de um período de 3 anos. Os resultados mostraram que ambos modelos de estimativa do BE apresentaram padrões semelhantes ao da torre micrometeorológica, com predominância da componente LE no verão e inverno e alternância entre estes componentes nos períodos de cobertura parcial. O modelo METRIC apresentou maior coerência com a torre, tanto em padrões como em magnitudes, além de uma maior coerência na distribuição espacial do fluxo de calor latente.

**PALAVRAS-CHAVE**: Produtos MODIS; ERA-Interim; *Eddy Covariance*

## INTRODUCTION

In agricultural sciences, one of the great challenges that scientific research has to face is the availability of methodologies that allow understanding the spatial variability of crop water conditions over large territorial extensions. This knowledge is extremely important especially to agriculture since water availability has been identified as the main restriction factor for reaching higher yields. To this end, the energy balance (EB), obtained from orbital images, can provide information that allow understanding the spatial distribution of surface water conditions. Also relevant is the fact that historical images and products from land monitoring programs allow to determine a time series.

There is no time series of the EB components available for Rio Grande do Sul yet. In addition to allowing a better understanding of the spatio-temporal variability of the surface physical properties, a time series can be used to generate statistical data for the water status of agricultural regions, which can subsidize policies for planning and minimizing risks in agriculture.

It is known that using terrain variables from a single point may not satisfactorily reflect the correct spatial variability in regional studies. As a consequence, the majority of the models used to estimate the EB components are based on combining surface data and satellite images (Allen et al., 2007, French et al., 2015, Kustas et al., 2016, Kilic et al., 2016), which can become complex sometimes due to restricted access to the necessary data and faulty compatibility between databases.

The objective of this work was to analyze the performance of the OSEB (One-Source Energy Balance) and METRIC (Mapping Evapotranspiration with Internalized Calibration) models in combination with the data from Reanalysis and satellite imagery to determine a consistent time series for EB components in southern Brazil. Therefore, this work contemplates the analysis and validation of results for further determination of a longer time series of the EB components.

## MATERIAL AND METHODS

The study site is in Rio Grande do Sul (Figure 1), a state in southern Brazil characterized by humid subtropical climate, with no dry season.

The OSEB (Tang et al., 2013, Boegh et al., 2002, Friedl, 2002 ) and METRIC (Allen et al., 2007) models that estimate the energy balance components combined with satellite images and reanalysis data were used to determine the time series and the adequacy of the procedure.

The data used in the study covered a period of three years, from 2009 to 2011. The data originated from three different sources: a) MODIS products (LP DAAC, 2016) such as surface temperature, albedo, vegetation index, and leaf area index; b) climatic data from the ERA-Interim reanalysis (ERA-INTERIM, 2016) such as air temperature and dew point temperature, global solar radiation, and wind speed; c) data from the micrometeorological station in Cruz Alta, RS (Lat: -28.6036; Long: -53.6736; Alt: 432 m) such as air temperature, global solar radiation, wind speed and EB, Rn (radiation balance), LE (latent evapotranspiration heat flux), H (sensible heat flux in the air), and G (sensible heat flux in the ground).

The micrometeorological station is located in a region characterized by intensive agriculture with emphasis on soybean crops in the summer and wheat in the winter. The measurements obtained in the station were defined as field reference values and used to verify the estimates of the EB components given by the OSEB and METRIC models. For this, the EB data were extracted using a 3x3 pixel window centered on the micrometeorological tower coordinates in Cruz Alta.

The adopted 8-day temporal resolution was based on the temporal resolution of the MODIS surface temperature product, totaling 138 dates analyzed over 3 years. The reanalysis data were imported and resampled to spatial resolution of 1km compatible with the MODIS images and average values were calculated for the 8-day period equivalent to the surface temperature.

The OSEB and METRIC models differ especially regarding the sensible heat flux calculation. In the OSEB model, H is obtained directly from the temperature gradient between the surface (obtained from the images) and the air (from the reanalysis data). In this model, the aerodynamic drag is obtained considering characteristics of the reference surface as proposed by Allen et al. (2008). On the other hand, the METRIC model uses the hot and cold anchor pixels for determining H from a self-calibration iterative process of the aerodynamic drag and vertical temperature differential in the first meters of the atmosphere. These anchor pixels consider the image water limits and the cold pixel is defined as $LE \approx 1.05ETo$ (reference evapotranspiration - Allen et al., 1998) and $H = Rn - G - LE$. The hot pixel takes into account the occurrence of a residual evaporation from the uncovered soil, $LE = E$ (soil evaporation obtained from the soil water balance proposed by Allen et al., 1998) and $H = Rn - G - LE$.

Because the region ecoclimatic conditions and the 1km-pixel resolution images make it difficult to detect the occurrence of completely non-vegetated pixels required by the METRIC model to determine the residual LE of the hot pixel, the hot pixels were assumed to have 50 % vegetation cover.

The results of the energy balance components Rn, LE, H, and G, obtained from the two models were compared to the reference measurements (micrometeorological tower) to determine the root mean square (RMSE) and mean bias (MBE) errors.

The reference evapotranspiration (ETo) data, estimated by the Penman-Monteith model as proposed by Allen et al. (2008) and obtained from the reanalysis data for the coordinates of the Cruz Alta (reference measurement tower), Uruguaiana, Pelotas and Bom Jesus stations were used to analyze the model responses to the spatial variability of the regional climatic conditions. For these locations, the days that the models had LE/Rn ratio greater than or equal to 50% were selected, and the LE vs. ETo dispersion graphs were built for both models.

## RESULTS AND DISCUSSION

The comparison between the reference dataset (micrometeorological station) and the partitioning of the EB parameters estimated by the OSEB and METRIC models was coherent over the analyzed period. It is noteworthy that the mean values and the standard deviations obtained for Rn and G were similar for both models (Table 1). The RMSE of the estimates were lower than 38 W m$^{-2}$, which was expected since Rn and G, in general, are the most easily obtained components (Timmermans et al., 2007, Tang et al., 2013). On the other hand, the LE and H components estimated by the models were significantly different while the RMSE was higher for the OSEB model compared to the METRIC model. The METRIC model overestimated H (negative MBE) whereas OSEB overestimated LE. It is noteworthy that although the tower measurements are being used as reference for evaluating the model estimates, differences are expected. The model estimates are obtained from data representing the average surface condition in a 1-km$^2$ area, in the best atmospheric condition over 8 consecutive days whereas the tower data are characteristic of the measurement point and represent the average condition over these 8 days.

The magnitude (Table 1) and temporal variability (Figure 2) of Rn measured in the micrometeorological tower were similar to the estimates obtained by the OSEB and METRIC models. The temporal variability throughout the year is typical and characteristic of subtropical climate regions since Rn is governed mainly by global solar radiation, which varies greatly between the summer and winter periods.

Also, the LE and H fluxes presented similar temporal patterns between the measurements recorded in the micrometeorological tower (Figure 2a) and the estimates obtained by the OSEB (Figure 2b) and METRIC (Figure 2c) models. LE was the predominant component (greater magnitude) during the crop development period, both summer and winter. In the partial vegetation coverage periods, between crop cycles, LE values dropped sharply and sometimes was even surpassed by H. The greatest differences between the LE and H components were observed during the winter crops for the METRIC model. Figure 2 also shows a significantly reduced data availability, from the total of 136 images analyzed with 8-day periodicity, the OSEB model had coherent results in 78 images while the METRIC in 93 images.

In the subsequent analysis, we tried to evaluate the spatial consistency of the LE component by comparing LE with ETo at different sites. The purpose was to address the question whether the OSEB and METRIC models can perform well despite the high variability observed in Rio Grande do Sul regarding the climate and surface conditions, which is a fundamental point for building the historical time series of the EB components in the state. Both models adjusted satisfactorily to the four sites investigated in this study. The determination coefficient, R$^2$, varied between 0.47 and 0.57 for the OSEB model (Figure 3) and between 0.53 and 0.66 for the METRIC model (Figure 3). The lowest R$^2$, less than 0.5, was calculated only for the OSEB model in the micrometeorological tower coordinates. Again, it is important to point out the uncertainties inherent to this comparison. LE (energy spent in the evapotranspiration process) and ETo (atmosphere evaporative demand) are distinct variables that have similar magnitudes only when the water supply to the soil is plentiful. The dataset used in this evaluation consisted of those days when the LE/Rn ratio was greater than or equal to 50%, which minimizes, but does not eliminate the differences.

## CONCLUSIONS

The OSEB and METRIC models present consistent patterns regarding the temporal distribution of the estimates of energy balance components.

The METRIC model can be considered more consistent than the OSEB since it yielded smaller errors and better adjustments for the spatial variability of the latent heat flux.

The METRIC model also has a greater number of dates with coherent results, and this is an important factor to be considered for building a time series capable of adequately representing the seasonal patterns of the EB components.

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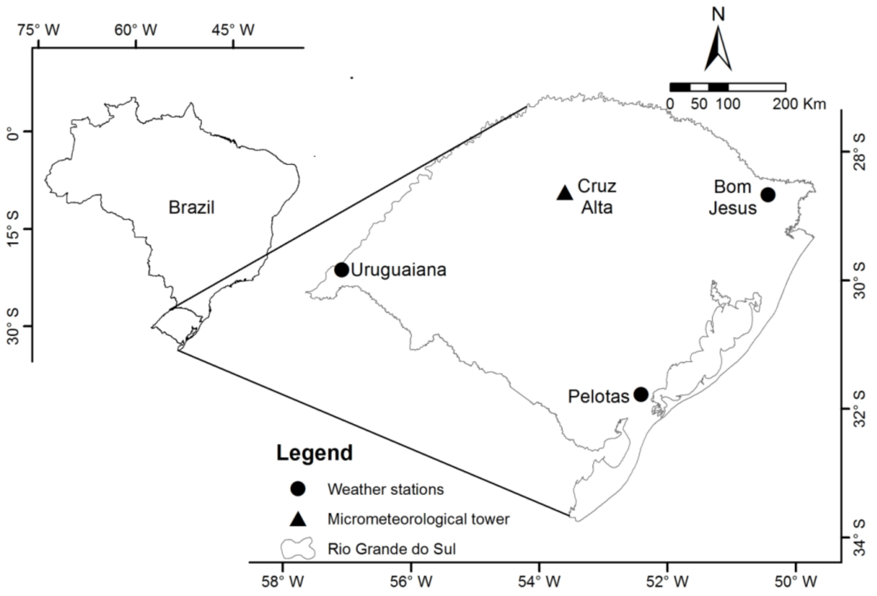
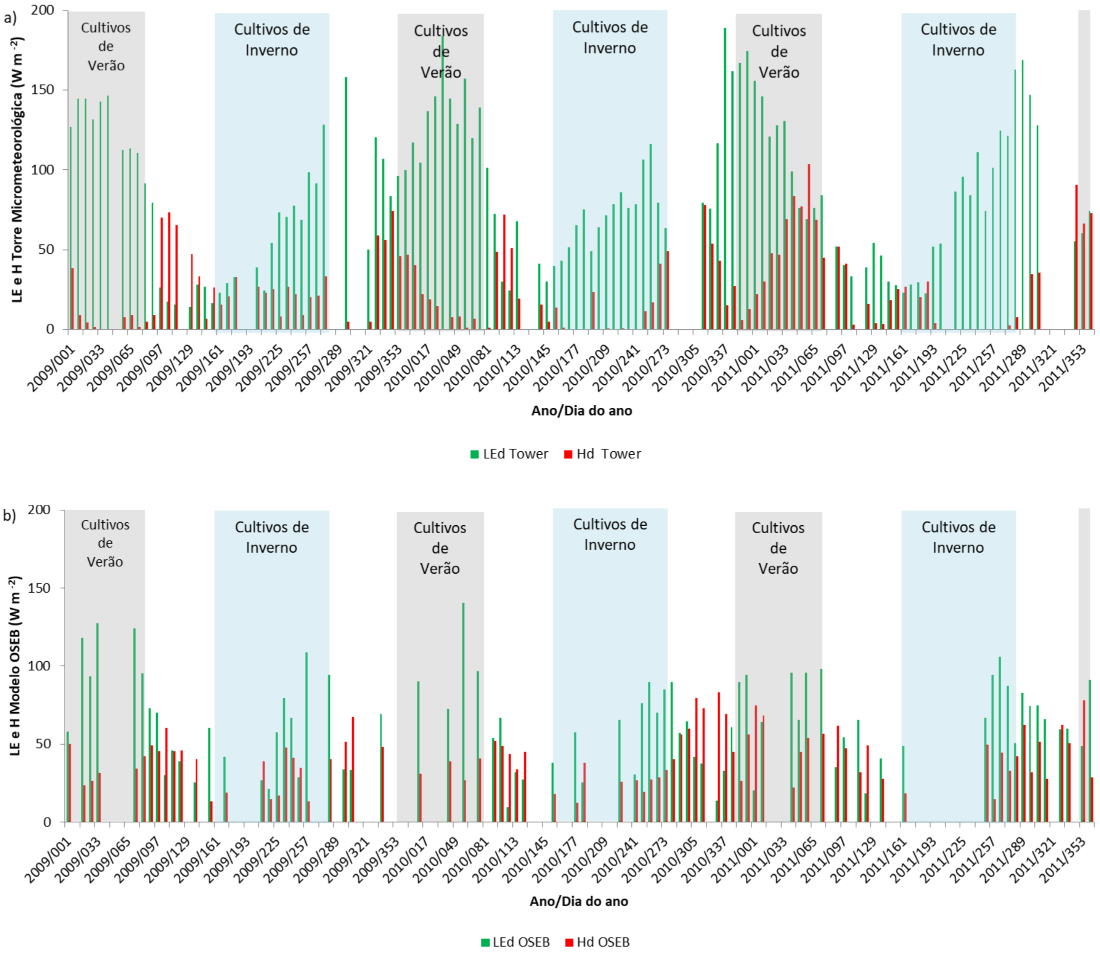


**Figure 1.** Local of study site in Rio Grande do Sul.

**Table 01.** Mean daily values of the EB components (W.m$^{-2}$) estimated by the OSEB and METRIC models and the errors between the estimates and the values measured in the reference micrometeorological tower.

| MODEL | Mean | Standard deviation | RMSE | MBE |
|---|---|---|---|---|
| **Rn** | 106 | 37 | 33 | -4 |
| **G METRIC** | 19 | 6 | 19 | -16 |
| **H METRIC** | 52 | 23 | 44 | -32 |
| **LE METRIC** | 52 | 32 | 42 | 22 |
| **Rn** | 114 | 34 | 38 | -8 |
| **G OSEBI** | 26 | 7 | 24 | -22 |
| **H OSEBI** | 40 | 17 | 61 | 40 |
| **LE OSEBI** | 65 | 30 | 59 | -43 |



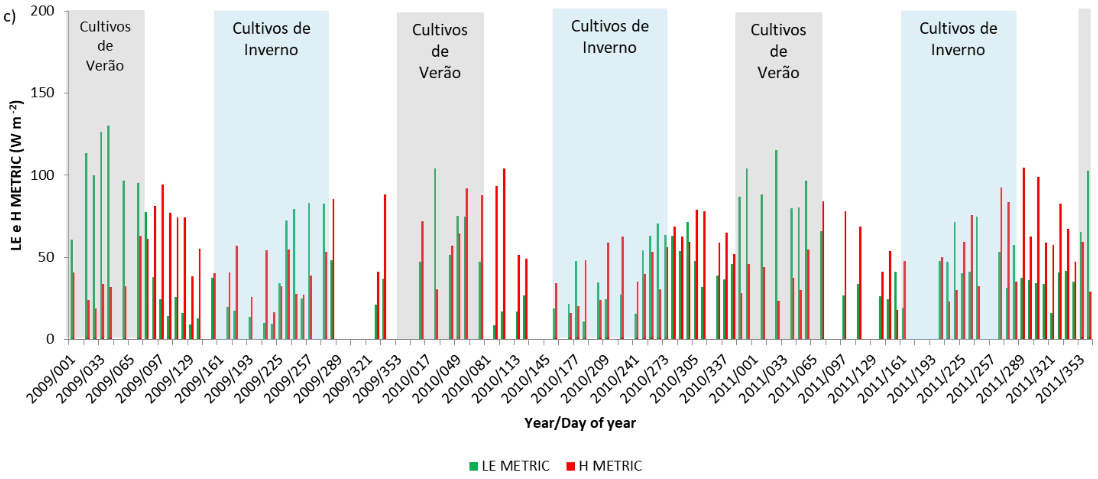
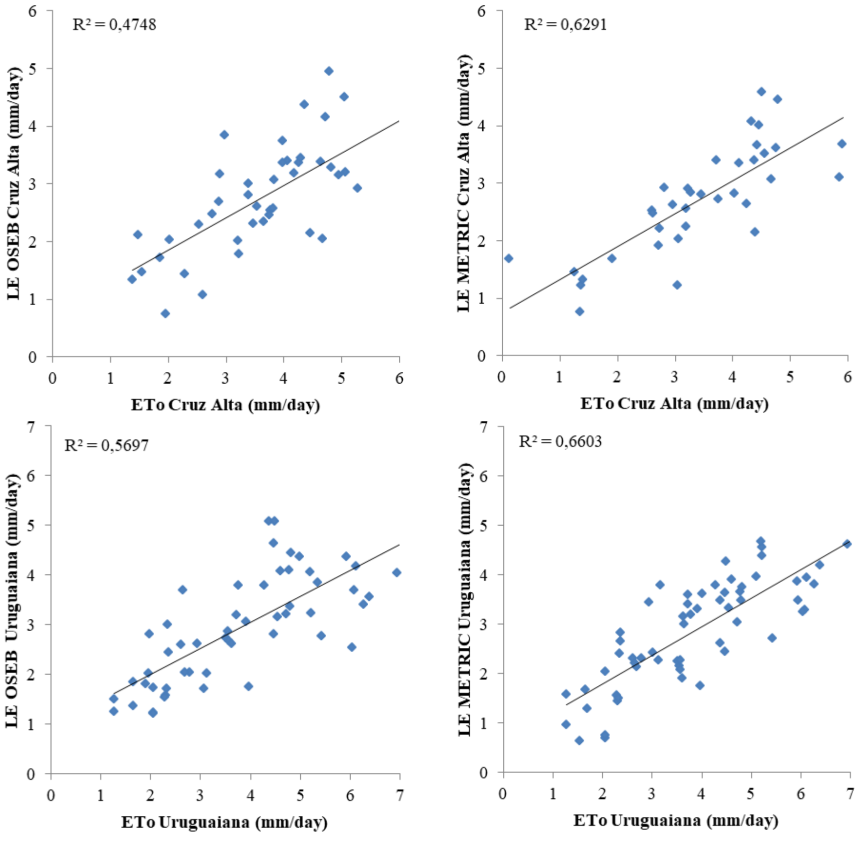


**Figure 2.** Temporal pattern of the latent (LE) and sensible (H) heat fluxes over a 3-year period (2009 to 2011) for the a) measurements recorded in the micrometeorological tower in Cruz Alta, RS, b) values estimated by the OSEB model, and c) values estimated by the METRIC model.



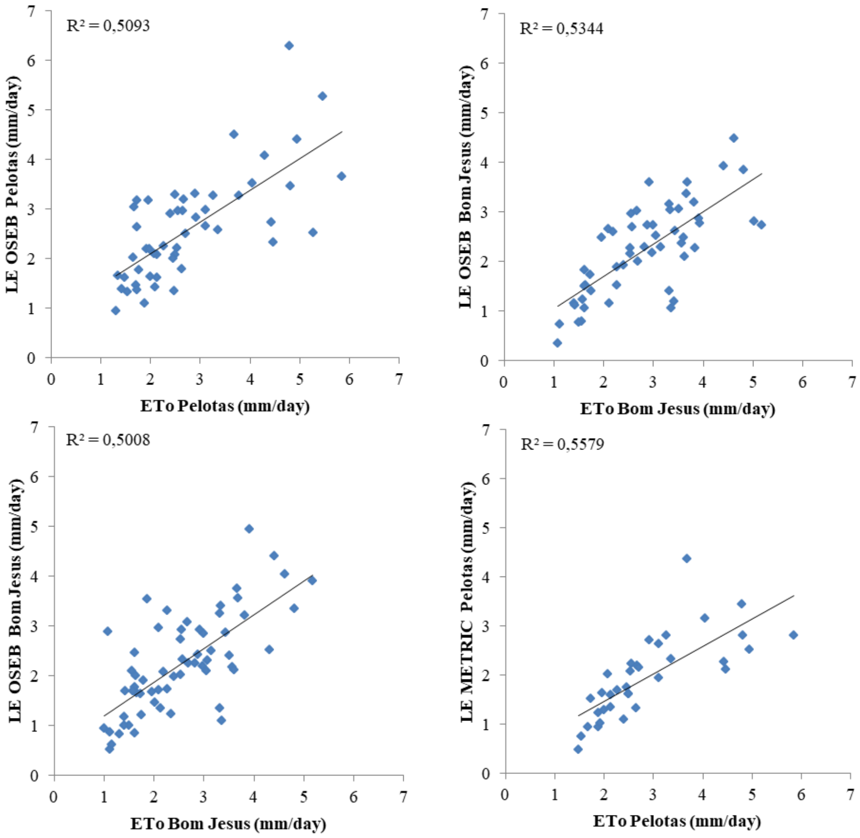


**Figure 3.** Dispersion plots for latent heat flux, LE (OSEB and METRIC models) versus reference evapotranspiration, ETo. The LE data were estimated for LE greater than or equal to 50% Rn.