EVAPOTRANSPIRATION ESTIMATION IN A CENTRAL PIVOT LOCATED IN RIO PRETO BASIN – BRAZIL: COMPARISON BETWEEN BOWEN RATIO METHOD AND SEBS

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ABSTRACT

Water management in Brazil is based on economic instruments, regulation (command-and-control) and regulatory practices that include permits for water withdrawals and enforcement. Enforcement activities are related to information gathering on actual water uses and verification of water permit conformity. One way of obtaining information about water consumption is through the use of remote sensing data, particularly the mapping of irrigated areas and the estimation of actual evapotranspiration with its inference on water withdrawals. The objective of this work was to evaluate the SEBS model – Surface Energy Balance System for estimating actual evapotranspiration of irrigated beans in a central pivot located in Rio Preto Basin (Brasilia – Brazil). The results show that SEBS is very sensitive to the quality of input data, particularly air and surface temperature. Successive corrections of surface temperature (atmospheric correction and calibration with in-situ data) were beneficial for simulated λE and ET output.

***Key words** — LANDSAT, irrigation, water resources*

1. INTRODUCTION

It is estimated that Brazil has around 12% of the total surface water of the world, but this amount is not evenly distributed in the Brazilian territory, 80% of the available water being concentrated in the Amazonian region, with only 5% of the national population [1]. Annual average rainfall varies from basin to basin between 841 mm year^{-1} in the Northeast of Brazil and 2.253 mm year^{-1} in the Amazonian region [1]. Considering seasonality, rainfall is higher in the summer of the Southern Hemisphere, and can be lower than 100 mm in the dry period in Central and Northeast Brazil [1].

Thus, for sustainable agricultural production, irrigation is a common practice in different parts of Brazil, as an additional supplement in dry spells or for the supply of total crop water demand. In Brazil, 67.2% of total water withdrawals from rivers and reservoirs are for irrigation purposes [2]. The total irrigated area in Brazil is estimated in 6.95 millions of hectares, and the forecast is to reach 10.01 millions of hectares in 2030 [2].

Regulatory instruments for water management include classification of water bodies (definition of usage and water quantity/quality standards), permits for water withdrawals, including return water and seepage, and enforcement. Enforcement activities are related to information gathering on actual water uses and verification of water permit conformity. Periodic and occasional field work is done by the enforcement team in different basins around Brazil.

The size of the Brazilian territory is 8,516,000 km². Due to the vast size of the area, it is not efficient to inspect compliance to water permits by means of field visits alone. Obtaining prior information about potential non-compliance is necessary before carrying out expensive field visits. One way of obtaining information about water consumption is through the use of remote sensing data, particularly the mapping of irrigated areas, estimation of actual evapotranspiration and subsequent inference on water withdrawals.

While it is possible to accurately measure evapotranspiration using local meteorological methods such as lysimeters, the Bowen Ratio and Eddy Covariance, it is only possible to have a high resolution estimation over large areas through the use of remote sensing data. In recent years, physically-based models have been developed to estimate actual evapotranspiration as a residue of the energy balance equation, including examples like TSEB – Two-Source Energy Balance [3], SEBAL – Surface Energy Balance Algorithm for Land [4] and SEBS – Surface Energy Balance System [5].

2. METHODOLOGY

2.1. Study Area

The experiment used in this work to evaluate SEBS was conducted inside a central pivot located in Rio Preto Basin, Eastern part of the Federal District – Brazil. The central pivot is located at the geographical position of 15°54’31” S, 47°25’12” W and has an irrigated area of 90.3 hectares, with mean elevation above sea level around 990 m. Beans were planted in the central pivot during the dry season, the period from planting to harvest was 30/04/2015 to 10/08/2015. Meteorological data was collected inside the central pivot using three Bowen Ratio stations (B.R. stations) between May 8 and August 5, 2015. The B.R. stations 3, 2, and 1 were positioned at respective distances of 240, 290 and 350 metres from the external boundary of the central pivot. Beans were planted on April 24, 2015 and harvesting was carried out on August 10, 2015.

2.2. General Methodology

Actual evapotranspiration (ETa) was estimated by SEBS model [5] using six of LANDSAT 7 and 8 images. Meteorological forcing variables used in the SEBS model were acquired from an in-situ meteorological station located 55 km from the central pivot. The SEBS model was first evaluated using meteorological in-situ data (from the Bowen Ratio station). The purpose of this step was to evaluate model structure, using parameters and forcing variables measured in-situ instead of satellite data. Later sensitivity analysis was conducted to identify the most critical model parameters/variables. Finally, SEBS output was compared against the Bowen ratio data from one station installed inside the central pivot for model and parametrization evaluation.

SEBS was run using six LANDSAT images (four LANDSAT-7 and two LANDSAT-8) in 5 different combinations of surface temperature and meteorological variables. For the surface temperature three different procedures were considered: 1. brightness temperature (Tb), 2. land surface temperature (LST), obtain by atmospheric correction of Tb, and 3. estimated surface temperature (Tsup), derived from in-situ meteorological measurements. For meteorological variables, two different sources were considered: 1. a meteorological station located 55 km from the central pivot (Ref.Station), 2. meteorological variables from the Bowen Ratio. Table 1 synthesizes the sources of data used in each run.

Table 1. Source of data for different SEBS models parametrization.

SEBS model	Ref. weather station	Bowen Ratio station	LANDSAT
I. Tb & Ref.Station	Air temperature, wind speed, incoming shortwave radiation and specific humidity		Albedo, emissivity, NDVI and brigtness temperature
II. LST & Ref.Station	Air temperature, wind speed, incoming shortwave radiation and specific humidity		Albedo, emissivity, NDVI and surface temperature
III. Tb & B.R.		Air temperature, wind speed, incoming shortwave radiation and	Albedo, emissivity, NDVI and brigtness temperature
IV. LST & B.R.		Air temperature, wind speed, incoming shortwave radiation and	Albedo, emissivity, NDVI and surface temperature
V. Tsup & B.R.		Surface temperature, air temperature, wind speed, incoming shortwave radiation and specific humidity	Albedo, emissivity and NDVI

3. RESULTS AND DISSCUSSION

The comparison between measured instantaneous λE and the parametrization simulated by different SEBS models is presented in figure 1. The model parametrization named “Tsup & B.R.” should be considered as a baseline to the comparison of other models, since surface temperatures were derived from in-situ meteorological measurements. A determination coefficient of 0.95 was obtained, but with a mean bias error (MBE) of -47 W m^{-2}. This could be related to SEBS estimation on the incoming longwave radiation. Albedo, emissivity and NDVI from LANDSAT were used in this model parametrization. The difference in model performance between III, IV and V highlights the importance of a precise estimation of surface temperature for the quality of simulated λE.

LANDSAT-7 only have a single thermal band, not enabling the utilization of a more precise method for atmospheric correction like a "split window algorithm" [6]. Another restriction was that non-atmospheric profile data were available for the correction of surface temperature, thus for the optical depth/visibility, an interactive process was performed to choose the appropriate visibility range [7]. As expected, models that used local meteorological data (Bowen Ratio) outperformed the ones that used the weather station data. Average RMSE of models III and IV was 66.5 W m^{-2} in comparison with 86 W m^{-2} of models I and II, and MBE is also lower (+12 W m^{-2} and -77 W m^{-2}). Air temperature was an average 1.9°C lower in the reference weather station, despite the fact that the mean daily air temperature was very close between the two stations. This is a huge difference for the energy balance consideration, and further application should consider utilization of other sources for hourly air temperature. Average wind speed was 2.2 m s^{-1} in the reference weather station and 3.0 m s^{-1} in the Bowen Ratio. Based on the sensitivity analysis, this difference of 0.8 m s^{-1} will increase 17 W m^{-2} in H, and -17 W m^{-2} in λE. Albedo derived from LANDSAT atmospheric corrected reflectance bands was in average 0.02 lower value than the albedo measured in the Bowen Ratio station. This impact on λE and Rn was in accordance to sensitivity analysis of -13.1 W m^{-2} and -15.1W m^{-2}.

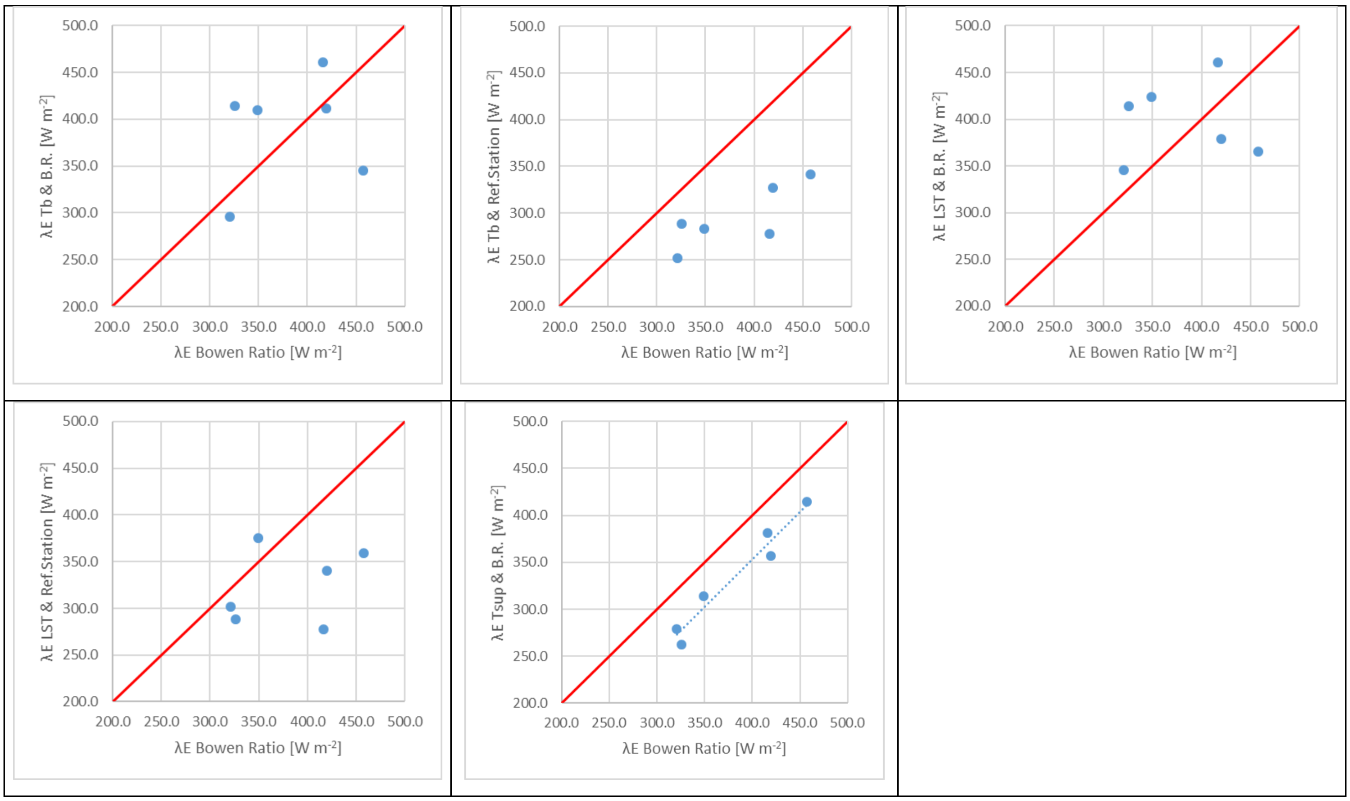

Figure 1. Scatter plot of instantaneous latent heat flux from Bowen Ratio and SEBS.

Correction of the surface temperature for atmospheric effects improved MBE and RMSE for the case of the reference weather station. A non-clear trend was observed for the models that used all meteorological variables from the Bowen Ratio station. But considering the baseline case (model V), it is possible to infer that RMSE will diminish with the improvement of surface temperature estimation. Uncertainty in surface temperature can be approached by introducing an excess resistance (rex) in H calculation, however, the estimation of rex as a function of z_{om} (roughness height for momentum transfer) and z_{oh} (surface roughness for heat transport) is uncertain as it requires assumptions about the constancy of the ratio between the two roughness lengths, as well as information about wind profile and atmospheric stability [8]. Models like SEBAL [4] use the spatial variability of the satellite radiometric temperature and correlates with the temperature gradient (dT) obtain in two extremes of the energy balance partitioning (cold and hot pixel). But uncertainty remains in the selection of the cold and hot pixels, and the assumption that extremes conditions are actually present in the scene. One possible alternative is applying a correction of LANDSAT surface temperature using the correlation with derived surface temperature from Bowen Ratio station data, thus relating the satellite radiometric temperature with the experimental derived surface temperature.

5. CONCLUSION

SEBS is very sensitive to the quality of input data, particularly air and surface temperature. Successive corrections of surface temperature are beneficial for simulated λE and ET output, including atmospheric correction and further possibility of calibration with in-situ data.

Derived albedo from LANDSAT atmospheric corrected reflectance bands is in the precision range of 0.01-0.03, and does not significantly impact λE and ET output.

Atmospheric correction of the LANDSAT thermal band is subject to uncertainty. This is due to the use of a single thermal band and the lack of atmospheric profile data in the case study period.

Further application of SEBS should considerer the calibration procedure with in-situ data and validation, and alternative methods to improve Tair, Tsup and dT spatialization.

6. REFERENCES

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