Net radiation estimation under pasture and forest in Rondônia, Brazil, with TM Landsat 5 images

Carlos Antonio Costa dos Santos¹
Raianny Leite do Nascimento¹
Antonio Ocimar Manzi²

¹ Universidade Federal de Campina Grande – UFCG/UACA
Avenida Aprígio Veloso, 882, Bodocongó, Campina Grande, PB, CEP: 58109-970, Brazil
carlostorm@gmail.com; raiannya@yahoo.com.br

² Instituto Nacional de Pesquisas da Amazônia – INPA/LBA
Avenida André Araújo, 2936, Aleixo, CEP 69060-001 Manaus, AM, Brazil
manzi@inpa.gov.br

Abstract. The main objective of this study is to obtain the spatial distribution of net radiation ($R_N$) in two contrasting vegetation covers (forest and pasture) through the SEBAL algorithm, and to analyze its performance when applied to tropical humid atmospheric conditions. This study was conducted in the state of Rondônia in northwestern Brazil, and were used four Landsat TM images, as well as, Digital Elevation Model data. The main results found can be summarized as follows: 1) The comparisons of the temporal distribution of estimated net radiation ($R_N$), using the SEBAL algorithm, with at surface measured values at the FNS (pasture) site have shown maximum and minimum MPE of 16% and 7%, respectively. For the Rebio Jaru (forest) site the maximum and minimum MPE were of 12% and 4%, respectively; 2) The albedo ($\alpha$) estimations by SEBAL for pasture and forest have shown similarities with previous study; 3) The correlation coefficients between estimated and measured values of $R_N$ and $\alpha$ are of 0.97 and 0.88, respectively. These results present the SEBAL as an important tool to be used in hydrological and environmental studies, and to obtain coherent temporal and spatial variations of surface characteristics, helping the improvement and validation of model parameterizations. However, the applications of remote sensing techniques in tropical humid climates are difficult, because exists a constant presence of clouds due the convective process.

Keywords: Humid climate, Amazonian rainforest, evapotranspiration, spatial variability

1. Introduction

Studies have shown that the Amazonian forests have a large influence on regional and global climates (Malhi et al., 2008). Thus, the conversion of forest to pasture and/or agricultural lands may cause large impacts on the regional hydrological, ecological and climatological processes (von Randow et al., 2004). The Large Scale Biosphere-Atmosphere Experiment in Amazonia (LBA) is an international research initiative led by Brazil. It is designed to create the new knowledge needed to understand the climatological, ecological, biogeochemical, and hydrological functioning of Amazonia, the impact of land use change on these functions, and the interactions between Amazonia and the Earth system.

Net radiation ($R_N$) is the most important parameter for compute the evapotranspiration, and is a driving force for others physical and biological processes (Samani et al., 2007). It is defined as the difference between the incoming and outgoing radiation fluxes (longwave and shortwave) at the Earth’s surface, and is used for different applications, such as: climate monitoring, weather forecast and agricultural meteorology (Bisht et al., 2005). Net radiation data are rarely available, and does not represent the spatial variability. Remote sensing is an innovative tool to observe land surface processes on a large spatial scale and low cost-effective (Cai and Sharma, 2010), hence several studies have tried to estimate $R_N$ through the combination of remote sensing observations with atmospheric and surface data (Bastiaanssen et al., 1998; Roerink et al., 2000; Bisht et al., 2005; Silva et al., 2005; Rimóczi-Paal, 2005; Samani et al., 2007; Ryu et al., 2008; Di Pace et al., 2008; Wang and Liang, 2009).
The main objective of this study is to obtain the spatial distribution of $R_N$ in two contrasting vegetation covers, tall tropical rainforest and short grassland, by using remote sensing techniques, and to analyze the performance of the SEBAL algorithm when applied to tropical humid conditions. The reason for this study is the deficiency of spatial $R_N$ informations and the fact of this algorithm has been vastly used in arid and semi-arid regions.

2. Materials and Methods

This study was conducted in the state of Rondônia in northwestern Brazil. The *terra firme* forest site is called Biological Reserve of Rio Jaru (Rebio-Jaru) located at 10° 4'48.00"S; 61°55'48.00"W and 120 m above the sea level. The grassland or pasture site is located in the cattle ranch called Fazenda Nossa Senhora (FNS) presenting geographical coordinates and elevation of 10°45'0.00"S; 62°22'12.00"W and 293 m above sea level. In Figure 1, it is found the geographical location of the study area, in Rondônia, with highlight to different land covers (pasture and forest).

![Figure 1: Geographical location of the study area, in Rondônia, with highlight to different land covers (pasture and forest)](image)

The list of meteorological variables measurements, instruments and measurement heights is shown in Table 1.

<table>
<thead>
<tr>
<th>Meteorological variable measurements</th>
<th>Instruments</th>
<th>Height (m) FNS (Pasture)</th>
<th>Height (m) Rebio Jaru (Forest)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incident and reflected shortwave radiation</td>
<td>Pyranometer Kipp &amp; Zonen (CM21)</td>
<td>6.5</td>
<td>19.3</td>
</tr>
<tr>
<td>Incident and emitted longwave radiation</td>
<td>Pyrgeometer Kipp &amp; Zoner (CG1)</td>
<td>6.5</td>
<td>19.3</td>
</tr>
<tr>
<td>Air temperature</td>
<td>Vaisala thermohygrometer HMP35A</td>
<td>8.3</td>
<td>60.0</td>
</tr>
<tr>
<td>Wind speed</td>
<td>Cup anemometer Vector A100R</td>
<td>9.3</td>
<td>61.1</td>
</tr>
<tr>
<td>Surface radiative temperature</td>
<td>Infrared sensor Heimann (KT15)</td>
<td>8.0</td>
<td>59.1</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Rain gauge EM ARG-100</td>
<td>0.5</td>
<td>60.3</td>
</tr>
</tbody>
</table>
Four Landsat Thematic Mapper (TM) images (DOY 187, 203, 219 and 267) were acquired around 10:00 a.m. local time in 2008. The spatial resolution for the reflectance bands of TM is 30 m x 30 m and 120 m x 120 m for the thermal band. It was necessary to resample the thermal band to the same size of the reflectance bands, as well as, the Digital Elevation Model (DEM) data which has 90 m resolution.

Algorithm for $R_N$ estimation

Surface Energy Balance Algorithm for Land (SEBAL) (Bastiaanssen et al., 1998) uses spectral radiances recorded by satellite sensors and meteorological measurements to solve the energy balance ($\text{net radiation} = \text{soil heat flux} + \text{sensible heat flux} + \text{latent heat flux}$) at the land surface (Gao et al., 2008). The obtaining of surface energy fluxes from any land surface require mainly energy inputs, i.e. shortwave and longwave radiation, and remote sensing can provide these inputs at a reasonable spatial and temporal scale (Norman et al., 1995). In this study, $R_N$ (energy input) was estimated using the relationship proposed by Bastiaanssen et al. (1998):

$$R_N = R_s \downarrow (1 - \alpha) + R_L \downarrow - R_L \uparrow - R_L \downarrow (1 - \varepsilon)$$

where $R_s \downarrow$ (W m$^{-2}$) is the incoming direct and diffuse shortwave radiation at surface; $\alpha$ (dimensionless) is the surface albedo, i.e. the ratio of reflected radiation to the incident shortwave radiation; $R_L \downarrow$ (W m$^{-2}$) is the incoming longwave radiation from the atmosphere; $R_L \uparrow$ (W m$^{-2}$) is the outgoing longwave radiation emitted from the surface to the atmosphere; and $\varepsilon$ (dimensionless) is the surface emissivity, which is the ratio of the radiant emittance from a grey body to the emittance of a blackbody (Melesse et al., 2008).

The incoming (direct and diffuse) shortwave radiation ($R_s \downarrow$) is a function of several factors, such as: solar elevation, solar radiation intensity, atmospheric transmittance and topographic correction. In this study, $R_s \downarrow$ was estimated as:

$$R_s \downarrow = \frac{I_0 \tau_{sw}}{\sin(\theta)d^2}$$

where $I_0$ is the solar constant (1367 W m$^{-2}$); $\theta$ is the solar inclination angle (radians); $d$ (astronomical units) is the relative distance between the Earth and the Sun; and $\tau_{sw}$ is the one way atmospheric transmissivity, computed as Allen et al. (1998):

$$\tau_{sw} = 0.75 + 2 \times 10^{-5} Z$$

where $Z$ (m) is the elevation, obtained from the Digital Elevation Model (DEM).

In SEBAL algorithm, the surface albedo is computed by correcting the albedo at the top of the atmosphere ($\alpha_{toa}$) for atmospheric transmissivity:

$$\alpha = \frac{\alpha_{toa} - \alpha_{path\_radiance}}{\tau^2}$$

where $\alpha_{path\_radiance}$ is the average portion of the incoming solar radiation across all bands that is back-scattered to the satellite before it reaches the surface of Earth, which values range between 0.025 and 0.04. Bastiaanssen (2000) recommends using $\alpha_{path\_radiance} = 0.03$.

$R_L \downarrow$ was estimated using the following equation:

$$R_L \downarrow = \sigma \varepsilon_a T_a^4$$

where $\sigma$ is the Stefan-Boltzmann constant ($\sigma = 5.67 \times 10^{-8}$ Wm$^{-2}$K$^{-4}$); $T_a$ is the near surface air temperature (K); and $\varepsilon_a$ is the atmospheric emissivity (dimensionless) obtained through an empirical equation proposed by Bastiaanssen et al. (1998):

$$\varepsilon_a = -0.85(\ln \tau_{sw})^{0.09}$$
The longwave radiation emitted from the surface of Earth to the atmosphere \( R_L \) was determined by the Stefan-Boltzmann law:

\[
R_L = \sigma \varepsilon T_S^4
\]

where \( \varepsilon \) is the surface emissivity and \( T_S \) is the surface temperature (K). In SEBAL, the surface emissivity is estimated using the Normalized Difference Vegetation Index (NDVI) and an empirically derived scheme (Bastiaanssen et al., 1998):

\[
\varepsilon = 1.009 + 0.047(\ln \text{NDVI})
\]

if NDVI > 0 and \( \varepsilon = 1 \) for NDVI < 0 (e.g. for water).

Surface temperature \( T_S \) was obtained from the thermal band (band 6 of the Landsat 5-TM sensor) radiance values using the simplified Plank’s equation and corrected using \( \varepsilon \):

\[
T_S = \frac{k_1}{\ln \left(\frac{k_1}{R} + 1\right)}
\]

where \( k_1 = 607.76 \text{ W m}^{-2} \text{ sr}^{-1} \mu\text{m}^{-1} \) and \( k_2 = 1260.56 \text{ K} \) are calibration constants, and \( R \) is a linear function of the Digital Number (DN) equal to:

\[
R = a \times \text{DN} + b
\]

where \( a = 0.055158 \text{ W m}^{-2} \text{ sr}^{-1} \mu\text{m}^{-1} \) and \( b = 1.2378 \text{ W m}^{-2} \text{ sr}^{-1} \mu\text{m}^{-1} \) (Melesse et al., 2008).

### 3. Results and Discussion

Tables 2 and 3 present the comparisons of the temporal distribution of estimated net radiation \( R_N \) and surface albedo \( \alpha \), using the SEBAL algorithm, with measured values at the FNS (pasture) and Rebio Jaru (forest) sites, respectively. The temporal distribution of NDVI in the different sites also is shown. In Table 2, the \( R_N \) maximum Mean Percentual Error (MPE) of 16% is shown for the DOY 267 and the minimum MPE of 7% for the DOY 219. Similar results are shown for \( \alpha \) values, with maximum and minimum MPE of 39% and 0% for the DOY 267 and 219, respectively. The NDVI values decreased from 0.48 to 0.12. This decrease occurs due the intensification of the dry season affecting the grass development (pasture); however, the minimum value of 0.12 is related with the burning activities in the area, which reduce drastically the NDVI values.

In Table 3, the \( R_N \) maximum MPE of 12% is shown for the DOY 203 and the minimum MPE of 4% for the DOY 267. Similarities are shown for \( \alpha \) values, with maximum and minimum MPE of 17% and 0% for the DOY 203 and 267, respectively. The NDVI values stayed almost constant during the study period, showing that the forest has a different behavior compared to pasture during the dry season. In both sites, the \( R_N \) estimated and measured values presented a significant increase for the DOY 267, showing the high solar energy supply in this region in clear-sky conditions during the dry season, which is used as driving force to different physical processes, such as: heat the surface, plants transpiration and water evaporation. All these processes are important for the environment, and the conversion of forest to pasture change drastically the net radiation at land surface.

The comparison between Tables 2 and 3 shows that \( R_N \) are higher in forested areas because they have lower \( \alpha \), i.e. reflect more solar (shortwave) radiation, when compared to deforested areas (pasture, for example). The surface albedo is the main factor that affects the land radiation balance and has frequently been considered in studies of regional and global climate. Oguntoyinbo (1970) found an average \( \alpha \) of 12% for forest and varying from 15 to 21% for no-forested areas, and Shuttleworth et al. (1984) identified an average \( \alpha \) of 12.3±0.2% for a tropical rainforest near Manaus, Brazil, as well as, Culf et al. (1996) found...
average \( \alpha \) of 13.4% and 18% for Amazonian forest and three pasture sites, respectively. All these results corroborate with those showed in this study.

The applications of remote sensing techniques in tropical humid climates are difficult. The main problem is the constant presence of clouds due to the convective process which is an important mechanism to heat the tropical atmosphere. To illustrate this difficult are shown in Figures 2 and 3 the diurnal behavior of the four radiation components (incoming and outgoing shortwave and longwave radiation) for the pasture and forest sites, respectively. In fact, every study day have shown cloud presences at noon or afternoon for the FNS and Rebio Jaru sites, except the DOY 187 at the Rebio Jaru station, which was a clear-sky day. The reason that was possible to apply remote sensing techniques and SEBAL algorithm to obtain the instantaneous \( R_N \) is because the Landsat satellite has a morning overpass in the study area (about 10:00 a.m. local time), and during this time no cloud interferences have been found.

**Table 2**: Comparison of the estimated net radiation (\( R_N \)) and surface albedo (\( \alpha \)), obtained by remote sensing algorithm, with measured values at the FNS site, as well as, the temporal distribution of the Normalized Difference Vegetation Index (NDVI) and the Mean Percentual Error

<table>
<thead>
<tr>
<th>DOY</th>
<th>( R_N ) (SEBAL) (Wm(^{-2}))</th>
<th>( R_N ) (Measured) (Wm(^{-2}))</th>
<th>MPE (%)</th>
<th>( \alpha ) (SEBAL)</th>
<th>( \alpha ) (Measured)</th>
<th>MPE (%)</th>
<th>NDVI (SEBAL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>187</td>
<td>500</td>
<td>450</td>
<td>11</td>
<td>0.18</td>
<td>0.21</td>
<td>-14</td>
<td>0.48</td>
</tr>
<tr>
<td>203</td>
<td>492</td>
<td>450</td>
<td>9</td>
<td>0.19</td>
<td>0.21</td>
<td>-10</td>
<td>0.39</td>
</tr>
<tr>
<td>219</td>
<td>497</td>
<td>465</td>
<td>7</td>
<td>0.22</td>
<td>0.22</td>
<td>0</td>
<td>0.31</td>
</tr>
<tr>
<td>267</td>
<td>663</td>
<td>573</td>
<td>16</td>
<td>0.11</td>
<td>0.18</td>
<td>-39</td>
<td>0.12</td>
</tr>
</tbody>
</table>

**Table 3**: Comparison of the estimated net radiation (\( R_N \)) and surface albedo (\( \alpha \)), obtained by remote sensing algorithm, with measured values at the Rebio Jaru site, as well as, the temporal distribution of the Normalized Difference Vegetation Index (NDVI) and the Mean Percentual Error

<table>
<thead>
<tr>
<th>DOY</th>
<th>( R_N ) (SEBAL) (Wm(^{-2}))</th>
<th>( R_N ) (Measured) (Wm(^{-2}))</th>
<th>MPE (%)</th>
<th>( \alpha ) (SEBAL)</th>
<th>( \alpha ) (Measured)</th>
<th>MPE (%)</th>
<th>NDVI (SEBAL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>187</td>
<td>574</td>
<td>548</td>
<td>5</td>
<td>0.10</td>
<td>0.12</td>
<td>-17</td>
<td>0.65</td>
</tr>
<tr>
<td>203</td>
<td>592</td>
<td>529</td>
<td>12</td>
<td>0.10</td>
<td>0.12</td>
<td>-17</td>
<td>0.72</td>
</tr>
<tr>
<td>219</td>
<td>607</td>
<td>550</td>
<td>10</td>
<td>0.12</td>
<td>0.13</td>
<td>-8</td>
<td>0.65</td>
</tr>
<tr>
<td>267</td>
<td>734</td>
<td>703</td>
<td>4</td>
<td>0.12</td>
<td>0.12</td>
<td>0</td>
<td>0.69</td>
</tr>
</tbody>
</table>

Figures 2a and 2b show the correlations between the estimated values of \( R_N \) and \( \alpha \) by SEBAL algorithm and measured values at the study stations (pasture and forest). The high correlations of \( R_N \) estimated (SEBAL) and measured values with correlation coefficient (R) of 0.97 are presented in Figure 2a, showing the efficiency of the simple schemes of SEBAL algorithm to obtain the radiative fluxes. The correlations between estimated and measured values of \( \alpha \) are shown in Figure 2b, which presents R value of 0.88.

The spatial distribution of \( R_N \) for the DOY 187, 203, 219 and 267 are shown in Figures 3a, 3b, 3c and 3d, respectively. The dark areas represent lower values of \( R_N \) while clear areas mean higher values of \( R_N \). In the Figures, lower values of \( R_N \) are in pasture lands or bare soil, which have higher albedo, and higher values are in forest and rivers which absorb more energy to use in the different physical processes. It is clear the environmental influences of the conversion of forest to pasture lands, such as the increase of the surface albedo, and in consequence the decrease of the net radiation. These studied parameters (net radiation and
surface albedo) have been evaluated with at surface observations and satellite measurements. Measured data are fundamental to validate model results, especially because they represent more realistically a specific studied site. However, they show operational difficulties, such as, are expensive to obtain and usually limited to a small area and do not represent the spatial variability. On the other hand, remote sensing is an important tool to obtain coherent temporal and spatial variations of surface characteristics, such as $R_N$ and $\alpha$, aiding improvement and validation of model parameterization.

**Figure 2:** Correlations between the estimated values by the SEBAL algorithm and measured values of net radiation ($R_N$) (a) and surface albedo (b) at the study area.

**Figure 3:** Spatial distribution of the net radiation ($R_N$) for different land covers (including pasture and forest), in the DOY 187 (a), 203 (b), 219 (c) and 267 (d) of 2008, in Rondônia

The findings presented in this study are helpful to understanding the spatial variability of the radiative fluxes, as well as, the net radiation, which is the fundamental quantity of
energy balance at the earth’s surface. The partitioning of $R_N$ into energy balance components, especially evapotranspiration, is firmly coupled with changes in land use and global climate conditions (Ryu et al., 2008). For regional water resources, through the evapotranspiration models which require $R_N$ as the core input parameter, an accurate estimation of $R_N$ is essential.

4. Conclusions
In this study, we employed the SEBAL algorithm to obtain the four radiation components and $R_N$ from four Landsat 5-TM images over an interface between two distinct land covers, forest and pasture, in Rondônia, Brazil. The main results found can be summarized as follows:

1) The comparisons of the temporal distribution of estimated net radiation ($R_N$), using the SEBAL algorithm, with at surface measured values at the FNS (pasture) site have shown maximum and minimum MPE of 16% and 7%, respectively. For the Rebio Jaru (forest) site the maximum and minimum MPE were of 12% and 4%, respectively.
2) The $\alpha$ estimations by SEBAL for pasture and forest have shown similarities with previous study.
3) The correlation coefficients between estimated (SEBAL) and measured values of $R_N$ and $\alpha$ are of 0.97 and 0.88, respectively.
4) These results present the SEBAL as an important tool to be used in hydrological and environmental studies, and to obtain coherent temporal and spatial variations of surface characteristics, helping the improvement and validation of model parameterizations. However, the applications of remote sensing techniques in tropical humid climates are difficult, because exists a constant presence of clouds due the convective process.

Acknowledgements
The authors are grateful for the research fellowship provided by National Council for Scientific and Technological Development (CNPq) to the first author and for supports the Project Nº. 556816/2009-9, as well as, for the scholarship provided by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) to the second author. This research was also supported by the Large Scale Biosphere-Atmosphere Program in Amazonia (LBA)/INPA. We thank the micrometeorology team of LBA in Ji-Paraná-RO and Manaus-AM, Brazil.

5. References


