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

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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 (α) 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 α 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-Paál, 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).

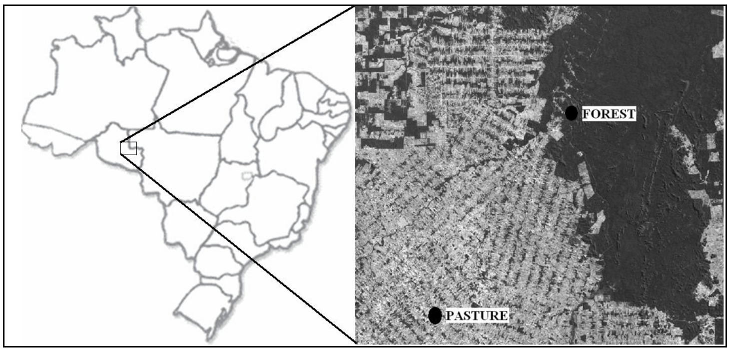


Figure 1: Geographical location of the study area, in Rondônia, with highlight to different land covers (pasture and forest)

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

Table 1: List of meteorological variables measurements, instruments and measurement heights in pasture and forest land covers in Rondônia

Meteorological variable measurements	Instruments	Height (m) FNS (Pasture)	Height (m) Rebio Jaru (Forest)
Incident and reflected shortwave radiation	Pyranometer Kipp & Zonen (CM21)	6.5	19.3
Incident and emitted longwave radiation	Pyrgeometer Kipp & Zoner (CG1)	6.5	19.3
Air temperature	Vaisala thermohygrometer HMP35A	8.3	60.0
Wind speed	Cup anemometer Vector A100R	9.3	61.1
Surface radiative temperature	Infrared sensor Heimann (KT15)	8.0	59.1
Rainfall	Rain gauge EM ARG-100	0.5	60.3

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 (*net radiation = soil heat flux + sensible heat flux + 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):

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

where $R_S\downarrow$ (W m^{-2}) is the incoming direct and diffuse shortwave radiation at surface; α (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 ε (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:

$$R_S \downarrow = \frac{I_0 \tau_{SW}}{\sin(\theta) d^2} \qquad (2)$$

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

$$\tau_{SW} = 0.75 + 2x10^{-5} Z \qquad (3)$$

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 (α_{toa}) for atmospheric transmissivity:

$$\alpha = \frac{\alpha_{toa} - \alpha_{path\_radiance}}{\tau^2} \qquad (4)$$

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:

$$R_L \downarrow = \sigma \varepsilon_a T_a^4 \qquad (5)$$

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

$$\varepsilon_a = -0.85(\ln \tau_{SW})^{0.09} \qquad (6)$$

The longwave radiation emitted from the surface of Earth to the atmosphere ($R_L\uparrow$) was determined by the Stefan-Boltzmann law:

$$R_L \uparrow = \sigma \varepsilon T_S^4 \tag{7}$$

where ε 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):

$$\varepsilon = 1.009 + 0.047(\ln NDVI) \tag{8}$$

if NDVI > 0 and ε = 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 ε:

$$T_S = \frac{k_2}{\ln(\frac{\varepsilon k_1}{R} + 1)} \tag{9}$$

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

$$R = a \times DN + b \tag{10}$$

where a = 0.055158 W m^{-2} sr^{-1} μm^{-1} and b = 1.2378 W m^{-2} sr^{-1} μm^{-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 (α), 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 α 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 α 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 α, 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 α of 12% for forest and varying from 15 to 21% for no-forested areas, and Shuttleworth et al. (1984) identified an average α of 12.3±0.2% for a tropical rainforest near Manaus, Brazil, as well as, Culf et al. (1996) found average α 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 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 (α), 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

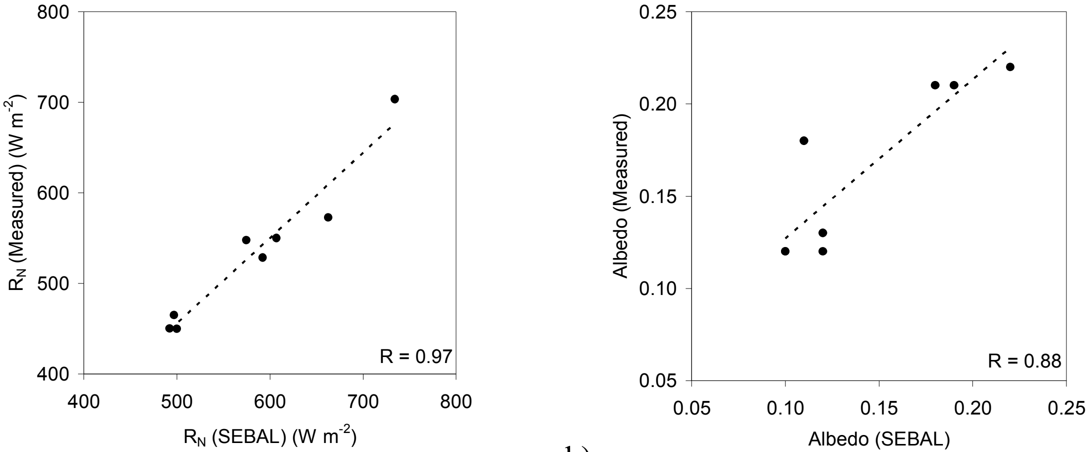
DOY	R_N (SEBAL) (Wm^{-2})	R_N (Measured) (Wm^{-2})	MPE (%)	α (SEBAL)	α (Measured)	MPE (%)	NDVI (SEBAL)
187	500	450	11	0.18	0.21	-14	0.48
203	492	450	9	0.19	0.21	-10	0.39
219	497	465	7	0.22	0.22	0	0.31
267	663	573	16	0.11	0.18	-39	0.12

Table 3: Comparison of the estimated net radiation (R_N) and surface albedo (α), 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

DOY	R_N (SEBAL) (Wm^{-2})	R_N (Measured) (Wm^{-2})	MPE (%)	α (SEBAL)	α (Measured)	MPE (%)	NDVI (SEBAL)
187	574	548	5	0.10	0.12	-17	0.65
203	592	529	12	0.10	0.12	-17	0.72
219	607	550	10	0.12	0.13	-8	0.65
267	734	703	4	0.12	0.12	0	0.69

Figures 2a and 2b show the correlations between the estimated values of R_N and α 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 α 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 α, aiding improvement and validation of model parameterization.



a) b)

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.

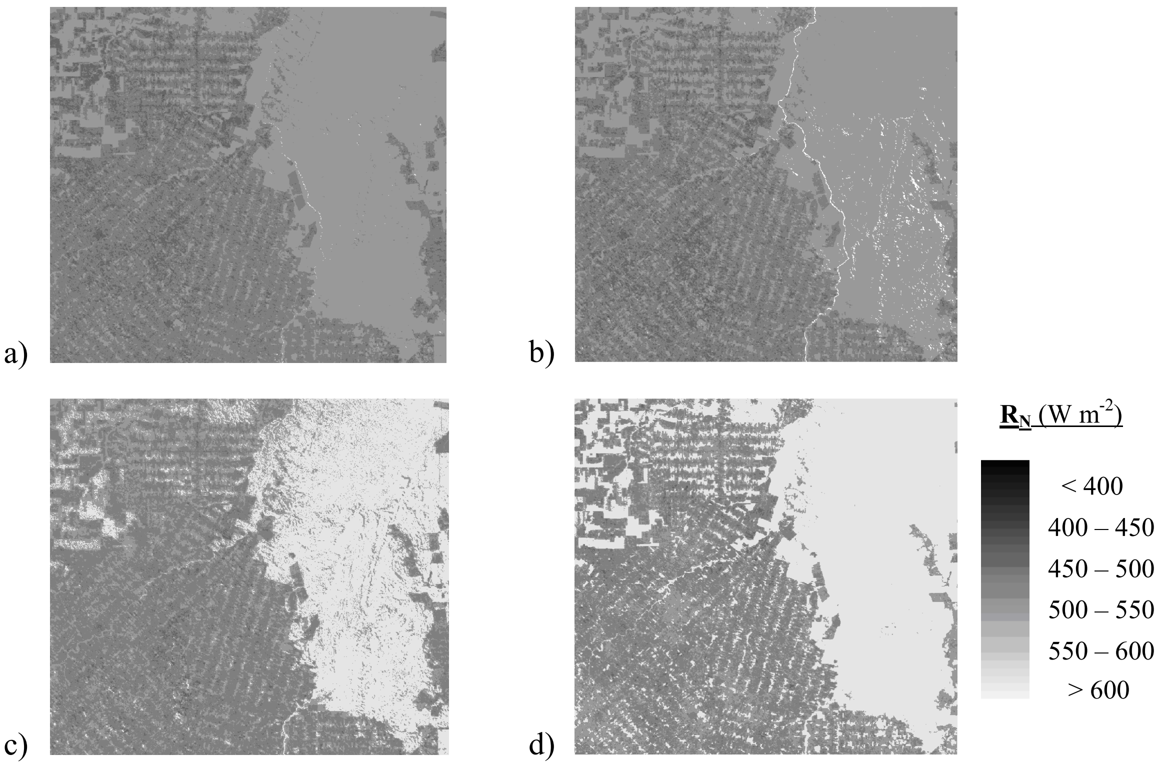


Figure 3: Spatial distribution of the net radiation (R_N) for different land covers (including pasture and forest), in the DOY 187 (a), 203 (b), 219 (c) and 267 (d) of 2008, in Rondônia

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 α 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 α 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.

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