Daily Net Radiation Over Different Land Cover Classes in Lagoa da Conceição Watershed, Florianópolis, Brazil

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Abstract. *Net radiation represents the difference between incoming and outcoming radiation over Earth's surface and is a crucial environmental parameter that can be derived from remote sensing data. This study aimed to retrieve daily net radiation over Lagoa da Conceição Watershed, in Florianópolis, Brazil. For that purpose, surface albedo was obtained from Landsat 8 imagery over eight land cover classes and radiation data was obtained from a weather station. The results showed mean daily net radiation estimates ranging from 64 Wm^{-2} over dunes to 136 Wm^{-2} over water surfaces, with important seasonal variations. The employed methods proved to be easy to apply and the results can indicate where further studies should focus.*

1. Introduction

Net radiation comprises the difference between downward and upward radiative fluxes on Earth's surface, including short- and longwave radiation. Several parameters are associated to surface's radiative balance, such as terrain characteristics, atmospheric conditions, hour of the day and day of year, and surface albedo and emissivity (Allen et al., 2007; Bastiaanssen et al., 1998; Pereira et al., 2002). Due to its inherent spatial variability, remote sensing data are of great interest for net radiation estimation (Allen et al., 2007; Silva et al., 2015; Ferreira et al., 2020).

The retrieval of net radiation is crucial for assessing and understanding atmospheric and hydrological processes, with a particular focus on evapotranspiration. According to Allen et al. (2007), estimating evapotranspiration is fundamental for the assessment of water balance and also for water planning and management.

As pointed out by Rech (2022), in Santa Catarina State, Southern Brazil, there are few studies regarding net radiation and evapotranspiration estimates. In Florianópolis, only four studies were found in this matter.

Given the importance of environmental monitoring and the lack of studies that estimate and analyze net radiation in Santa Catarina, this study aims to estimate daily net radiation over Lagoa da Conceição Watershed in Florianópolis (Brazil). Specifically, we aim to retrieve daily net radiation estimates from combining Landsat 8 and weather station data, and to quantify it over different land cover classes.

2. Materials and Methods

2.1 Study Area and Selected Data

The present study analyzed daily net radiation over Lagoa da Conceição Watershed, located in the insular portion of Florianópolis (Santa Catarina, Brazil). The watershed has an area of 75 km^2, from which nearly 21 km^2 constitute a lagoon. Köppen's climate classification at the study area is Cfa, i.e., humid subtropical zone (oceanic climate), without dry season and with hot summer (Alvares et al., 2013). Climatic normals for the region indicate mean annual temperature and precipitation of 21.1 °C and 1,766 mm, respectively (INMET, 2022).

Albedo was derived from Landsat 8 Operational Land Imager (OLI) bands (Level 2, Collection 2, Tier 1 surface reflectance data). Considering only scenes with cloud cover equal to or less than 5% within the study area, 101 images (acquired between April 2013 and May 2023) were selected. The scenes were processed through Google Earth Engine Python API (Gorelick et al., 2017). Radiation data were obtained from the weather station A806 (27°36'00" S, 48°37'12" W), operated by Brazilian National Institute of Meteorology (INMET).

The results were sampled over eight land cover classes within the study region: dunes (DUN), forest (FOR), herbaceous vegetation (HER), deep (LCD) and shallow (LCS) water of the lagoon, Restinga vegetation (RES), silviculture (SIL), and urbanization (URB).

2.2 Data Processing

According to De Bruin (1987), daily net radiation can be calculated by:

$$R_n = (1 - \alpha)R_s - 110\tau_{sw} \quad (1)$$

where R_n is daily net radiation (Wm^{-2}), α is surface broadband albedo, R_s is daily downward shortwave radiation (Wm^{-2}) and τ_{sw} is daily atmospheric transmissivity, which is the ratio of R_s to daily solar radiation on top of atmosphere, R_{toa}. The factor that multiplies τ_{sw} can be locally calibrated using in situ measurements, which were not available to the study area.

The formulation with which R_{toa} was obtained is presented by Vianello and Alves (2012) and includes the following expressions:

$$R_{toa} = 37.6d^2(H \sin\phi \sin\delta + \cos\phi \cos\delta \sin H) \quad (2)$$

$$H = |\cos^{-1}(-\tan\phi \tan\delta)| \quad (3)$$

where d is the relative Earth-Sun distance, ϕ is the latitude, and δ is the Sun declination (Duffie and Beckman, 2013).

Surface albedo was obtained with the model proposed by Angelini et al. (2021):

$$\alpha = (47.39\rho_2 - 43.72\rho_3 + 16.52\rho_4 + 28.31\rho_5 + 10.72\rho_6 + 10.29\rho_7 + 3.66) \times 10^{-2} \quad (4)$$

where ρ_2 to ρ_7 are Landsat 8 surface reflectance OLI bands 2 to 7.

3. Results and Discussion

As can be seen in the previous section, only albedo was derived from Landsat 8 data. The other variables of Equation 1 are constant to each image, and their values are summarized in Table 1.

Table 1. Summary of daily solar radiation estimates on surface and on top of atmosphere (MJm^{-2}), and atmospheric transmissivity.

Variable	Mean	SD	Min	$Q_{25\%}$	Median	$Q_{75\%}$	Max	IQR
R_{toa}	28.51	6.09	21.16	23.36	27.19	33.10	40.76	9.74
R_s	18.36	5.09	8.45	14.55	17.85	20.93	31.79	6.38
τ_{sw}	0.64	0.06	0.39	0.60	0.64	0.68	0.78	0.08

R_{toa} is a parameter that depends exclusively on latitude and Sun positioning, unlike R_s, which also depends on atmospheric conditions. Atmospheric components absorb and scatter the incoming solar radiation, and only a fraction of it effectively reaches Earth's surface. In the case of Lagoa da Conceição Watershed, this fraction represents around 64% at the considered dates, as indicated by τ_{sw}.

Figure 1 depicts R_s distribution through the seasons. There's a clear approximation between the colder (Fall and Winter) and between the warmer (Spring and Summer) seasons. The mean difference between them was of about 10 MJm^{-2}.

It's important to keep in mind that these metrics were calculated for 101 clear-sky days out of more than a decade. A more robust analysis of these variables should include daily data, which would probably generate lower means for R_s and τ_{sw} due the inclusion of cloudy and partially cloudy days. Additionally, Fall and Winter represent more than 76% of the considered scenes, as most of Spring and Summer images have high cloud cover. Hence, it's possible that the actual difference between R_s at colder and warmer seasons is lower; despite Spring and Summer have greater R_{toa}, they also have a greater proportion of cloudy days compared to Fall and Winter, as the results pointed out.

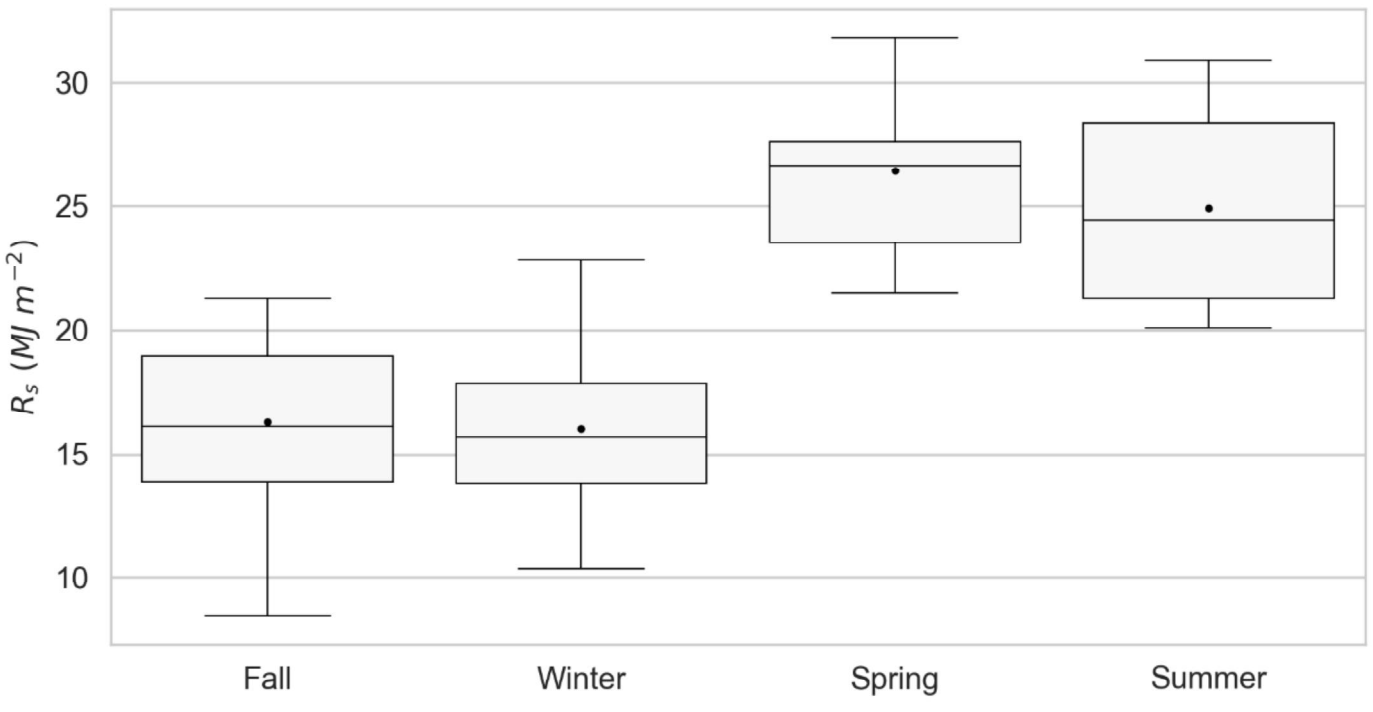

Figure 1. Box plots of R_s (MJm^{-2}) grouped by season (black dots = means).

In turn, mean α and R_n values are presented in Figure 2. Considering the sampled pixels, albedo ranged from 0.03 over water to 0.37 over dunes on average. Notably, LCS presented mean albedo lower than LCD, even though one could expect the opposite when looking at Figure 2a. Water surfaces have issues due to their very low reflectances in all spectral bands and are greatly affected by atmospheric correction (Rech et al., 2023).

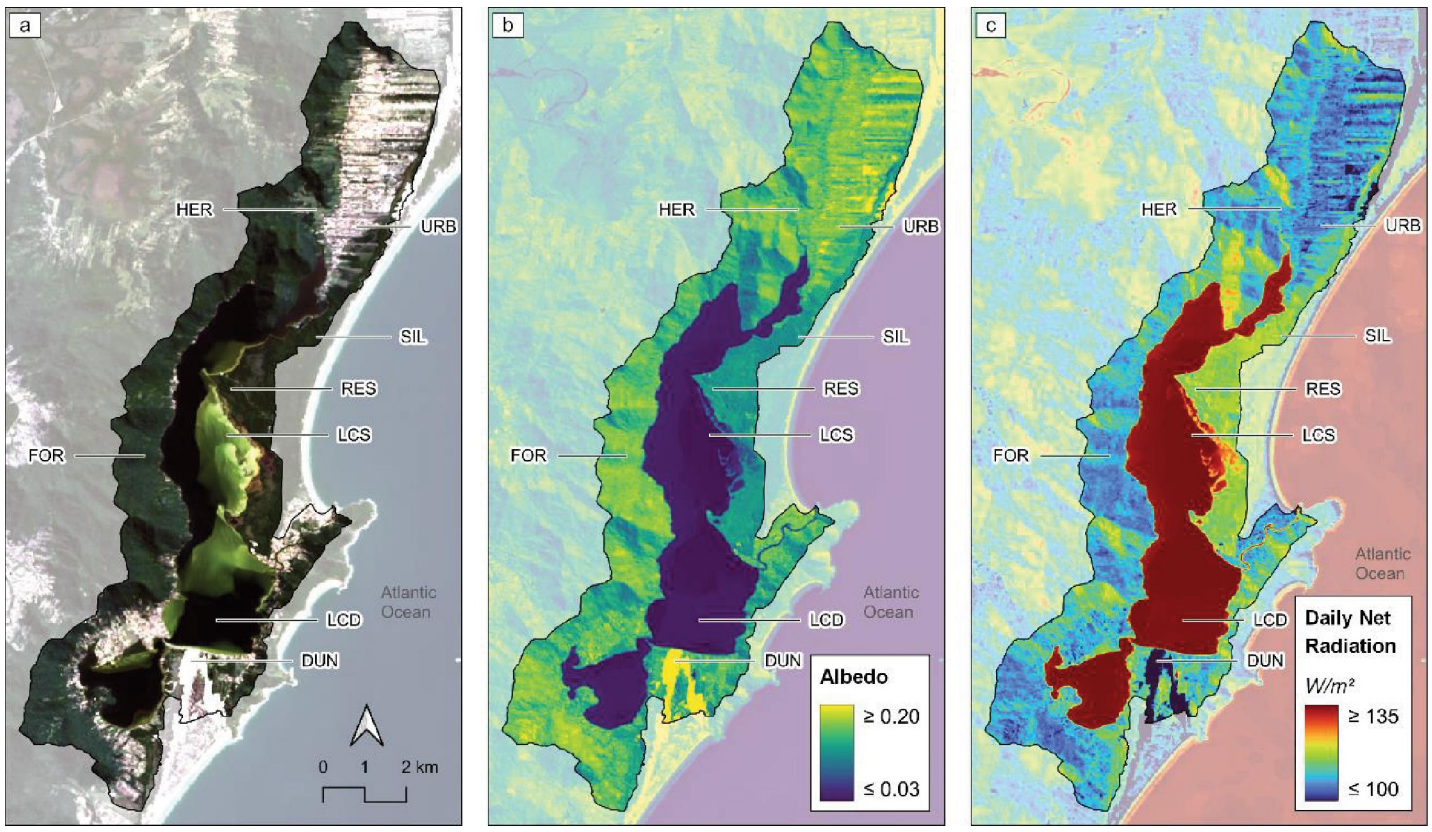

Figure 2. Mean a) true color composite, b) albedo, and c) daily net radiation (Wm^{-2}) over the study area.

Daily net radiation and albedo are negatively correlated quantities. Higher albedo values result in greater amounts of reflected radiation, which subsequently leads to smaller differences between downward and upward fluxes, R_n. In the summary of Table 2 it's possible to observe the mean daily net radiation of the different land cover classes. The highest values were registered over LCS and LCD (around 135 Wm^{-2}), while the lowest mean R_n was registered over DUN (64 Wm^{-2}).

Table 2. Summary of daily net radiation (Wm^{-2}) estimates sampled over different land cover classes (n = 96,218).

Class	N	Mean	SD	Min	$Q_{25\%}$	Median	$Q_{75\%}$	Max	IQR
DUN	7,248	63.6	32.0	9.6	37.1	57.1	84.2	169.8	47.1
FOR	39,964	111.6	44.7	34.7	75.1	103.5	136.0	237.0	60.9
HER	6,680	107.3	43.4	35.3	71.6	100.6	132.2	234.8	60.7
LCD	4,419	134.9	51.6	50.5	94.6	127.4	162.1	269.5	67.4
LCS	9,467	135.6	51.9	50.4	94.7	128.4	163.1	274.9	68.4
RES	15,572	115.4	45.9	40.2	78.1	108.5	140.3	236.6	62.2
SIL	7,131	118.3	47.2	42.0	80.3	111.4	144.8	239.7	64.4
URB	12,985	107.0	41.8	36.3	72.8	100.0	130.3	224.4	57.5

We can notice that, except for water and dunes, all classes presented similar R_n estimates, varying from 107 Wm^{-2} over URB to 118 Wm^{-2} over SIL on average. Their mean albedos vary from 0.16 to 0.11 over URB and SIL, respectively.

While surfaces such FOR and URB may exhibit similar radiative fluxes, their predominant types of energy are expected to be significantly different. In surfaces with high water availability, we can expect predominance of latent heat fluxes, which are linked to evaporation and evapotranspiration. On the other hand, sensible heat fluxes are expected to be the main component of the energy balance over surfaces such as URB, where water availability is low. This differentiation, for instance, leads to urban areas being warmer.

Silva et al. (2015) obtained R_n varying from 60 Wm^{-2} to 229 Wm^{-2} over agricultural and woody savanna areas in a subtropical watershed. They employed Landsat 5 data and found mean absolute error, mean relative error and root mean square error of 8.3 Wm^{-2}, 8.4% and 10.4 Wm^{-2}, respectively, when comparing the results with in situ measurements. Similarly, Debastiani et al. (2018) used a single Landsat 8 image to estimate the radiation balance over São Joaquim National Park, in Santa Catarina. They found R_n from 143 to 198 Wm^{-2} over silviculture, 144 to 204 Wm^{-2} over forests and 160 to 206 Wm^{-2} over water (in January, i.e., during Summer).

7. Conclusion

As expected, solar radiation (R_s) showed to be susceptible to seasonal variations, and represented 64% of solar radiation on top of atmosphere (R_{toa}) on average for the considered days. Daily net radiation (R_n) mean values are affected by a great predominance of Fall and Winter images, which represent 77 out of 101 scenes. Thus, more in-depth analyses shall consider a balance between seasons, as the input variables have strong seasonal behavior.

The employed methods for estimating daily net radiation over Lagoa da Conceição Watershed proved to be effective and easy to apply. Further studies can explore continuous daily data in order to remove the bias caused by Landsat 8 data availability, as well as include terrain considerations for better representation of the area.

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