Original Article

CHANGES IN PAST GLOBAL SOLAR RADIATION BASED ON CLIMATE MODELS AND REMOTE SENSING IN THE STATE OF RIO DE JANEIRO, BRAZIL

MUDANÇAS OCORRIDAS DA RADIAÇÃO SOLAR GLOBAL PASSADA BASEADO EM MODELOS CLIMÁTICOS E SENSORIAMENTO REMOTO NO ESTADO DO RIO DE JANEIRO, BRAZIL

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ABSTRACT: The objective of this study was to perform a temporal and spatial analysis of the changes in the past global solar radiation based on climate models and remote sensing data in the State of Rio de Janeiro, Brazil for the baseline period (1961-1990). Data from two climate models - the Canadian Centre for Climate Modelling and Analysis and Geophysical Fluid Dynamic Laboratory, were used for the A1B intermediate scenario, data from Conventional Weather Stations and orbital sensor Moderate Resolution Imaging Spectroradiometer (MODIS) MODIS Land Cover Type (MCD12Q1). The results of the Spatial Dependence Degree indicate that the best model to represent the global solar radiation is CCCMA-Exponential dry 70.01 and rainy 0.21 respectively. It was possible to verify that in places where the areas are occupied by forests there was reduction of global solar radiation for both dry and rainy periods of approximately 13 MJ $m^{-2}d^{-1}$. These results indicate that these forest areas can function as islands of freshness, while maintaining the thermal comfort balanced. It was concluded that the dry period had the highest values of solar radiation compared to the rainy (57%), which can be justified by the occurrence of fires in Rio de Janeiro.

KEYWORDS: Geotechnologies. Landscape change. Numerical models. Urban climate.

INTRODUCTION

It is widely known that the increase in the occurrence of environmental disasters caused by anthropic actions that lead to global and regional climate change is a topic currently widely debated around the world, fomenting discussions in the scientific and governance sphere over the Planet (DELGADO et al. 2014).

According to the report The Human Cost of Weather Related Disaster prepared by the United Nations Office for Disaster Reduction (UNISDR) and the Epidemiology Research Center in Disasters (CRED), Brazil is the only country in the Americas that is on the list of the 10 countries with the largest number of people affected by the environmental disasters between 1995 and 2015. The report informs that about 90% of the disasters are related to the effects of climate change (KILL, 2016).

In Brazil, the state of Rio de Janeiro is where the greatest number of natural disasters occurs, mainly related to floods and landslides. According to Civil Defense estimates, the state is the most vulnerable, having been affected by several serious events in recent years (SELUCHI et al., 2016).

Global climate-related changes have been observed over the past century, mainly as a result of the global average air temperature rise at 0.85°C in the period 1880-2012 (IPCC, 2014). The main cause attributed to global warming is the increase in emissions of greenhouse gases (GEE) in the atmosphere from the pre-industrial period to the present time. Prolonged periods with extreme air temperatures are highly detrimental to the agricultural productivity, livestock, increased energy demand and electricity consumption, and damage to public health (BITENCOURT et al., 2016).

In the context of climate changes, numerous physical-mathematical models have been used by several researchers in different regions of the globe and scenarios, such as the HadRM3 regional model used in the Western Amazon region by Justino et al., 2013 and Delgado et al. (2014) and the CIMP5 model used by Zomer et al. (2014) in Yunnan Province, China.

Several authors highlight the importance of solar radiation in agroforestry systems, in a study of solar radiation accumulation for the production of

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Cordia americana seedlings in the Santa Maria forest nursery, the authors stated that in the cultivation of seedlings, the water and nutrients supply are not present as limiting factors due to the possibility of control, whereas solar radiation controls the biomass production (TRAUTENMÜLLER et al., 2016).

In this context, the objective of this work was to relate the changes of the global solar radiation passed through the basement through climate models and remote sensing in the State of Rio de Janeiro-Brazil.

MATERIAL AND METHODS

Study area

Global solar radiation ($MJm^{-2}d^{-1}$) data from eight grid points coinciding with municipalities in Rio de Janeiro were used, generated by the output of CCCMA (Canadian Center for Climate Modeling and Analysis) and GFDL (Geophysical Fluid Dynamic Laboratory) for the intermediate scenario A1B based on the Intergovernmental Panel on Climate Change (IPCC) report for the baseline period of 30 years (1961-1990). In this period, the accumulated monthly global solar radiation was calculated for the two models and for data from Conventional Meteorological Stations (CMS) of the National Institute of Meteorology (INMET), in according Allen et al. (1998). For INMET, it was needed to use boundary stations because there were no station data coincident with all the grid points of the models (Table 1). The grid points coinciding with the municipalities of Porciúncula and Cambuci (RJ) presented the same boundary station and it wasneeded to exclude one of the points to avoid duplicate data, we chose Porciúncula.

Table 1. Grid pointrelation of models and boundary stations.

Grid Points	Lat (°)	Lon (°)	boundary station	Lat (°)	Lon (°)	Distance (km)
Angra dos Reis	-23.01	-44.32	Angra dos Reis	-23.01	-44.32	0
Cachoeiras de Macacu	-22.46	-42.65	Nova Friburgo	-22.28	-42.53	39.1
Cambuci	-21.58	-41.91	Itaperuna	-21.21	-41.89	83.2
Campos dos Goytacazes	-21.75	-41.32	Santa Maria Madalena	-21.95	-42.01	133
Casimiro de Abreu	-22.48	-42,20	Cordeiro	-22.02	-42.38	97.8
Paraty	-23.22	-44.71	Ubatuba	-23.39	-45.01	73.6
Porciúncula	-20,96	-42.04	Itaperuna	-21.21	-41.89	43.6
Resende	-22.47	-44.45	Resende	-22.47	-44.45	0

Descriptive statistics

After estimating the monthly global solar radiation accumulated in according Allen et al. (1998), the descriptive statistics for the two CCCMA, GFDL and INMET models were performed. The statistical performance of the models was evaluated considering the simple linear correlation (r), coefficient of determination (r^2), standard error of rstimation (EPE) and Willmott's index of agreement (d). By the evaluation of the Willmott's coefficient (1981 and 2005) it was possible to determine the agreement between the observed (EMCs) and estimated (CCCMA and GFDL)data.The Willmott's coefficient values range from zero, to no agreement, to 1, to the perfect agreement.

$$r = \frac{\sum O_i P_i}{\sqrt{\sum O_i^2 \sqrt{\sum P_i^2}}} \quad (1)$$

$$r^2 = \frac{\sum_{i=1}^{n} \left(P_i - \overline{O}\right)^2}{\sum_{i=1}^{n} \left(O_i - \overline{O}\right)^2} \quad (2)$$

$$EPE = \sqrt{\frac{\sum \left(O_i - P_i\right)^2}{n-1}} \quad (3)$$

$$d = 1{,}0 - \frac{\sum_{i=1}^{N} \left(P_i - O_i\right)^2}{\sum \left(\left|P_i - \overline{O_i}\right| + \left|O_i - \overline{O_i}\right|\right)^2} \quad (4)$$

In which, observed value Oi is global solar radiation ($MJm^{-2}d^{-1}$) in the i-th observation, mean values observed in the i-th observation and n the number of samples e i = 1, 2, ... n, Pi is the estimated value of global solar radiation ($MJm^{-2}d^{-1}$) in the i-th observation.

Geostatistical Analysis

For the geostatistics calculations, the software ArcGis version 10.2 and the method of interpolation of Ordinary Kriging (KO) were used, values of the nugget effect, range, reach, RMSE and the degree of spatial dependency (GDE) were obtained through the*Geostatistical Analyst*tool of ArcGis 10.2, by using global solar radiation for the spherical, exponential and gaussian model for CCCMA and GFDL. For the analysis of the geostatistics results, the method proposed by Cambardella et al. (1994) was used, in the case of GDE <25%, the data have a strong spatial dependence, for 25% <GDE <75% the data have moderate spatial dependence and for GDE> 75% the data have a weak spatial dependence.After the analysis of performance and choice of the best model, through Cambardella et al. (1994) GDE was calculated only for the model chosen for the annual periods, dry (May to October) and rainy (November to April).

Remote Sensing

In addition, raster-based images the soil use and occupation in the state of Rio de Janeiro extracted from the Moderate Resolution Imaging Spectroradiometer (MODIS) MODIS Land Cover Type (MCD12Q1) sensor with 500-m spatial resolution were added to the maps. The method used was based on Ataíde (2012), with modifications.

RESULTS AND DISCUSSION

Figure 1 presents the results of the descriptive statistics for the two climatic models evaluated for the baseline period. The results provided by the CCCMA (A) model were close to 1 (0.94), indicating greater agreement with the meteorological station data than the GFDL (B) model (0.92), an average difference of 2.14%.

The correlation data of the CCCMA and GFDL models presented similar values (r = 0.20), not influencing this variable in the indication of the best performance model.The EPE presented the largest error for the CCCMA model (0.89 $MJm^{-2}dia^{-1}$) than for the GFDL model (0.49 $MJm^{-2}dia^{-1}$), a significant difference (81% higher) indicating a smaller adjustment of the CCCMA model by the descriptive statistical evaluation of EPE.The coefficient of determination (r^2) resulted in a better value for the GFDL model (0.25), reflecting better performance. However, there is little difference between the models (16%), and the adjustment is good for both according to the coefficient of determination.

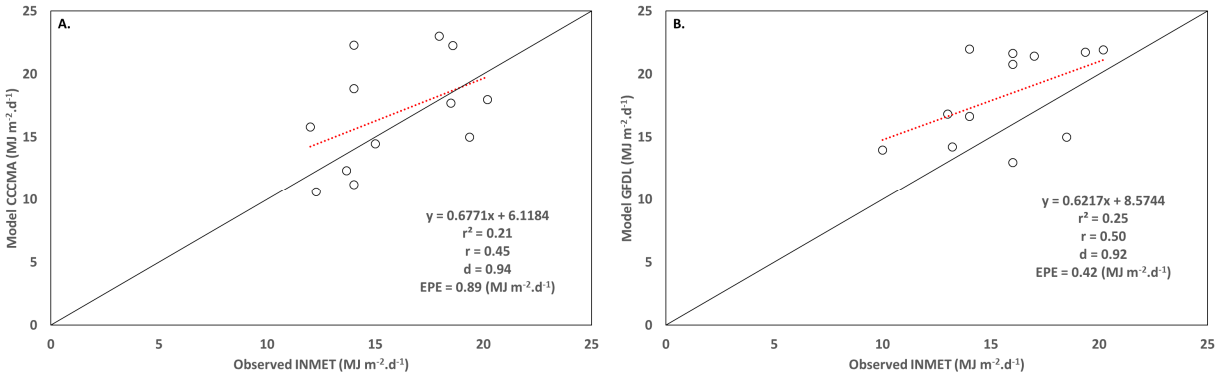


Figure 1. Statistical performance indicators for annual output values of the CCCMA (A) and GFDL (B) models for the baseline period (1961-1990) for the state of Rio de Janeiro.

The GDE values were better for the exponential CCCMA model, indicating a better adjustment of this model for the State of Rio de Janeiro (Table 2). From this result, the GDE calculation was performed for the dry (May to October), rainy (November to April) and annual (January to December) periods of the State of Rio de Janeiro (Table 3) to evaluate performance in Different times of the year in the region.The result of the GDE for the CCCMA was better for the exponential model in the three periods, indicating strong spatial dependence for the rainy season and moderate spatial dependence for the dry season, according to Cambardella et al. (1994).

Table 2. Degree of spatial dependency (GDE) for the CCCMA and GFDL models (baseline 1961-1990).

		CCCMA	GFDL
GDE	Spherical	23.09	54.48
	Exponential	0.15	43.95
	Gaussian	36.31	59.67

Table 3. Result of degree of spatial dependency (GDE) calculation for the CCCMA model for the dry and rainy season (baseline 1961-1990).

		Dry	Rainy
GDE	Spherical	71.36	32.36
	Exponential	70.01	0.21
	Gaussian	71.64	50.68

Overlapping the MODIS product raster (MCD12Q1) to the global solar radiation data of the CCCMA-Exponential model for the annual period (Figure 2), it was possible to notice that the highest values of global solar radiation were on the Northern Fluminense and Baixadas Litorâneas (18.07 $MJm^{-2}dia^{-1}$) and Northwest Fluminense (17.49 $MJ.m^{-2}.dia^{-1}$), with vegetation predominance of mosaic of cultivation and natural vegetation, savanna, fragments of rainforest and urban constructions (NASA EOSDIS, 2017). Low values are found in the Médio Paraíba (16.43 $MJ.m^{-2}.dia^{-1}$) and Costa Verde (16.10 $MJ.m^{-2}.dia^{-1}$), with land use corresponding to urban construction and savanna in the Médio Paraíba and rainforest in Costa Verde (NASA EOSDIS, 2017).

The lowest values of global solar radiation may be associated with the rainfall events, cloudiness, and the striking presence of the Atlantic Forest biome (ROCHA et al., 2003). In the southern region of the state, according to André et al. (2008) can be explained by the conformation of the coast and the influence suffered by the high humidity coming from the ocean. The configuration of Serra do Mar relief acts directly in the state climate. The southern region receives larger amounts of rain due to the influence more direct from the ocean. On the other hand, the Fluminense North and Northwest regions are located farther away from the ocean, receiving fewer amounts of rain and cloudiness, which causes a significant increase in global solar radiation in these regions.

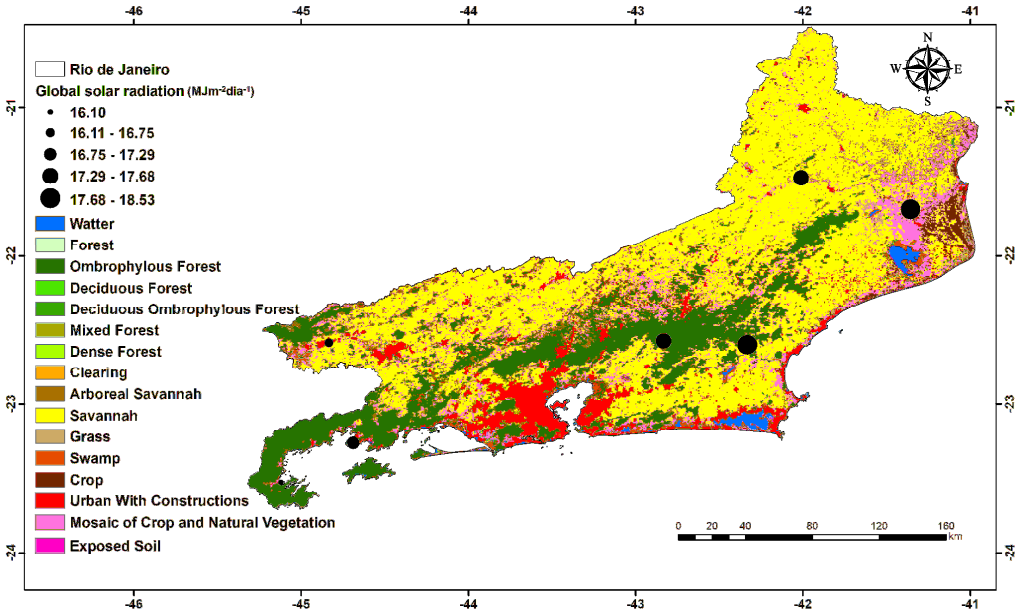


Figure 2. Global solar radiation mean and soil use and occupation for the annual period (1961-1990) in the state of Rio de Janeiro.

The areas with the lowest values of global solar radiation are shown in Figure 1, these areas can function as islands of freshness, mainly in the A1B intermediate scenario ofIPCC, for the baseline climatology (1961-1990). According to the study developed by Delgado et al. (2014) in the State of Acre, the water bodies help to maintain the islands of freshness, since these islands do not reflect the energy received in the infrared range and still present low reflectivity. Another study emphasizes the river corridors as controllers of the environmental quality of a region, one of its attributions being the establishment of adequate climate control conditions (ÉRICA et al., 2011). In a study of thermal comfort in three cities (Campinas, Bauru and Presidente Prudente) of the State of São Paulo Labaki et al. (2012) concluded that the tolerance for hot weather conditions is lower for users of thepassing space than for the wooded spaces, indicating that these spaces should receive special attention and optimize the thermal comfort of their users. In the work, it is evident that the non-forested areas present a greater gradient of the global solar radiation above 18 $MJ.m^{-2}.dia^{-1}$advancing in the Northeast region of Rio de Janeiro, characterizing a region of islands of heat and deficit thermal comfort.

In general, the areas occupied by urban constructions, savanna and mosaic of cultivation presented higher values of radiation and the smallest ones being quantified in regions occupied by forest.For the rainy season, through the analysis of Figure 3, it is possible to verify that the geographic distribution of global solar radiation is similar to the annual period. The global solar radiation data for the dry period (Figure 4) were higher for the Northern Fluminense and Baixadas Litorâneas (14.22 $MJm^{-2}dia^{-1}$), areas occupied by mosaicof cultivation and natural vegetation and rainforest (NASA EOSDIS, 2017). The lowest values were observed in the region of Costa Verde (13.32 $MJm^{-2}dia^{-1}$), Médio Paraíba (13.50 $MJm^{-2}dia^{-1}$) and Northern Fluminense (13.50 $MJm^{-2}dia^{-1}$), regions with predominant rainforest, urban constructions and savannah, respectively.

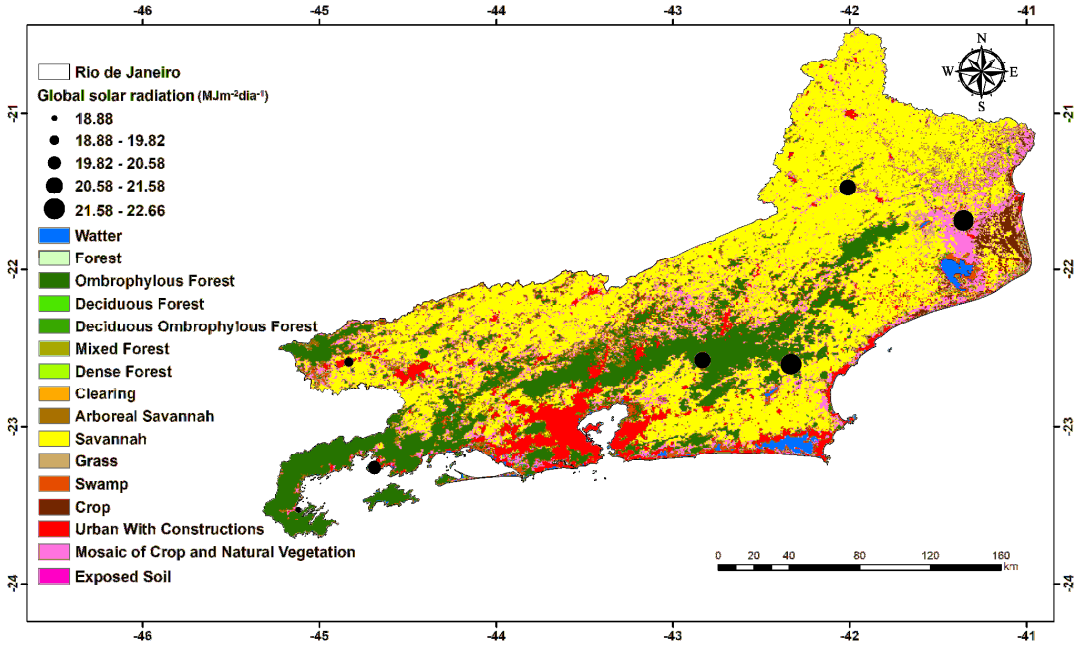


Figure 3. Global solar radiation and soil use and occupation for the rainy season in the state of Rio de Janeiro.

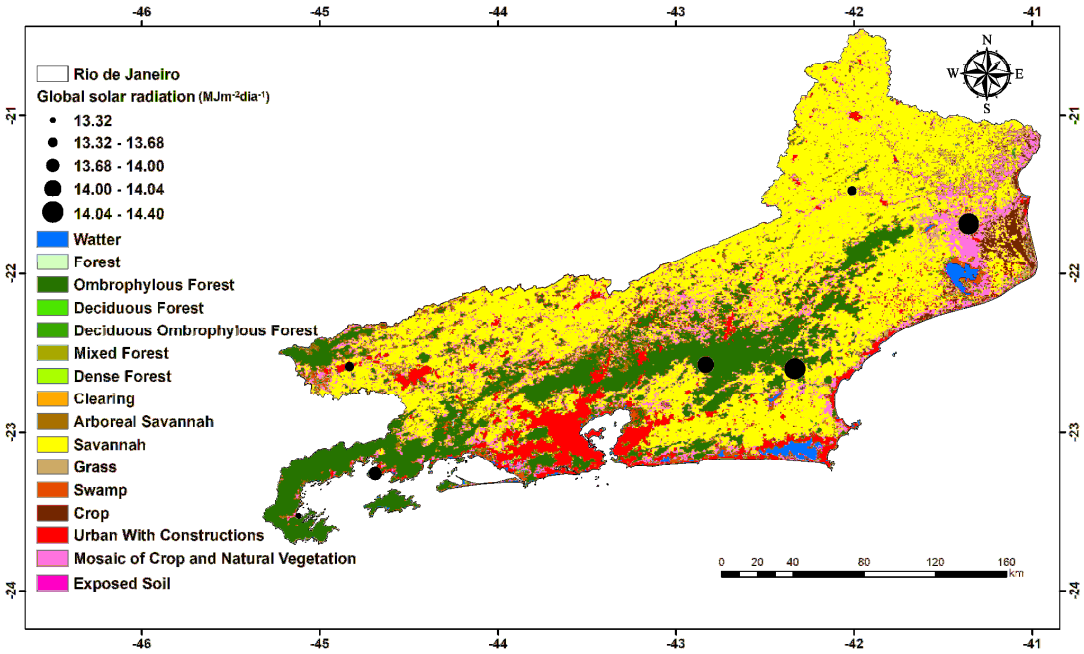


Figure 4. Global solar radiation and soil use and occupation for the dry season in the state of Rio de Janeiro.

Results similar to those obtained in this study were found by Delgado et al. (2012) and Costa et al. (2010), in which the authors verified that the lowest values of global solar radiation occurred in urban areas and with little or no vegetation. The authors concluded that this pattern is due to the fact that the concrete and the sand, used in the constructions, have thermal absorption properties, which causes the heat (irradiated) to be concentrated, resulting in areas of greater thermal field.

The presence of clouds in the atmosphere strongly modulates the absorption of global solar radiation, as they are good distributors of short-wave radiation. However, although the rainy season had a higher cloud presence and higher values of humidity, which would contribute to the reduction of global solar radiation absorption, in the dry period a global solar radiation value higher than the rainy season was observed in about 57% (CLIMANÁLISE, 2017). In addition, today's tropical rainforests, after centuries of exploitation and millions of deforested hectares, now have large areas converted into pastures, crops and urban centers, contributing to the increased environmental degradation and burning (FIALHO; ZINN 2014; CAÚLA et al., 2015). The loss of biodiversity due to anthropogenic reasons, followed by large episodes of forest fires, burnings and extreme droughts, leads to devastating consequences for the forest systems in the state of Rio de Janeiro, besides economic losses and an increase in social problems (Caúla et al., 2015).

CONCLUSIONS

The GFDL model presented higher values of GDE, indicating a lower representativeness. The CCCMA model associated with the use of the exponential equation is the model with the best representativeness for the State of Rio de Janeiro.

In the rainy season, the model represents better than in the dry season, which can be explained by the GDE value of the rainy season being much smaller (0.21) than for the dry period (70.01). Locations in which the areas are occupied by rainforest presented lower values of solar radiation, corroborating the best adjustment of the CCCMA model using the exponential equation.

In the dry season, the highest values of solar radiation were verified in comparison to the rainy season (57%), which can be justified by the occurrence of fires in Rio de Janeiro.

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RESUMO: O objetivo deste estudo foi realizar uma análise temporal e espacial das mudanças ocorridas da radiação solar global passada baseado em modelo climáticos e sensoriamento remoto no Estado do Rio de Janeiro, Brasil para o período baseline (1961-1990). Utilizaram-se dados de dois modelos climáticos o Canadian Centre for Climate Modelling and Analysis) e Geophysical Fluid Dynamic Laboratory para o cenário intermediário A1B, dados de Estações Meteorológicas Convencionais e do sensor orbital Moderate Resolution Imaging Spectroradiometer (MODIS) MODIS Land Cover Type (MCD12Q1). Os resultados do Grau de Dependência Espacial indicam que o melhor modelo que representa a radiação solar global é o CCCMA-Exponencial seco 70.01 e chuvoso de 0.21 respectivamente. Foi possível verificar que em locais onde as áreas são ocupadas por florestas houve redução da radiação solar global para os dois períodos seco e chuvoso de aproximadamente 13 $MJ.m^{-2}.dia^{-1}$. Estes resultados indicam que estas áreas de florestas podem funcionar como ilhas de frescor, mantendo o conforto térmico equilibrado. Conclui-se que o período seco apresentou maiores valores de radiação solar em comparação ao chuvoso (57%), que pode ser justificado pela ocorrência de queimadas no Rio de Janeiro.

PALAVRAS-CHAVE: Geotecnologias. Mudança da paisagem. Modelos numéricos. Clima urbano.

REFERENCES

ANDRÉ, R. G. B.; MARQUES, V. S.; PINHEIRO, F. M. A.; FERRAUDO, A. S. Identificação de regiões pluviometricamente homogêneas no estado do Rio de Janeiro, utilizando-se valores mensais. **Revista Brasileira de Meteorologia**, São José dos Campos, v.23, n.4, p.501-509, 2008.

ATAÍDE, K. R. P. **Modelagem de determinação da evapotranspiração real para o bioma cerrado por meio de dados de sensoriamento orbital**. Tese de Doutorado. Universidade de Brasília, Brasília, 176p, 2012.

BITENCOURT, D. P., FUENTES, M. V., MAIA, P. A., & AMORIM, F. T. Frequency, Duration, Spatial Coverage, and Intensity of Heat Waves in Brazil. **Revista Brasileira de Meteorologia**,São José dos Campos v. 31, n. 4, p. 506-517, 2016.

CAMBARDELLA, C. A.; MOORMAN, T. B.; NOVAK, J. M.; PARKIN, T. B.; KARLEN, D. L.; TURCO, R. F.; KONOPKA, A. E. Field scale variability of soil properties in central Iowa soil. **Soil Science Society of America Journal**, New York, v. 58, p. 1501-1511, 1994.

CAÚLA, R. H.; OLIVEIRA-JÚNIOR, J. F.; LYRA, G. B.; DELGADO, R. C.; HEILBRON FILHO, P. F. L. Overview of fire foci causes and locations in Brazil based on meteorological satellite data from 1998 to 2011. **Environmental Earth Sciences**, Amsterdã, v. 74, p. 1497-1508, 2015.

Climanálise. Produtos Climanálise INPE/CPTEC. 2017.[cited 12January 2017]. Available from: http://climanalise.cptec.inpe.br/~rclimanl/boletim/cliesp10a/bonatti.html.

COSTA, D. F.; SILVA, H. R.; PERES, L. F. Identificação de ilhas de calor na área urbana de Ilha Solteira - SP através da utilização de geotecnologias. **Engenharia Agrícola**, Jaboticabal, v. 30, n. 5, p. 974-985, 2010.

DELGADO R. C.; RODRIGUES, R. A.; PESSÔA, C. S.; DAHER, M. Uso do sensoriamento remoto na estimativa dos efeitos de ilhas de calor. **Revista Brasileira de Ciências Ambientais**, Belém,v. 25, n. 9, p. 69-80, 2012.

DELGADO, R. C.; DE OLIVEIRA-JUNIOR, J. F.; GOIS, G.; LYRA, G. B. Cenários Climáticos da Radiação Solar Global Baseados no Modelo Regional HadRM3 para o Estado do Acre. **Floresta e Ambiente**, Seropedica, v. 21, n. 4, p. 417-428, 2014.

ÉRICA, L. Ó. I. S.; LABAKI, L. C.; SANTOS, R. F. Efeitos de diferentes estruturas de vegetação ciliar sobre as variáveis de microclima e a sensação de conforto térmico. Effects of different riparian vegetation structures on microclimatic variables and sensation of thermal comfort. **Revista do Instituto Florestal**, v. 23, n. 1, p. 117-136, 2011.

FIALHO, R. C.; ZINN, Y. L. Changes in Soil Organic Carbon Under Eucalyptus Plantations in Brazil: A Comparative Analysis. **Land Degradation & Development**, Amsterdã, v. 25, p. 428–437, 2014.

IPCC- Intergovernmental Panel on Climate Change. **Climate Change 2014**: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 2014. 151 pp.

JUSTINO, F., OLIVEIRA, E. C., RODRIGUES, R. A., GONÇALVES, P. H. L., SOUZA, P. J. O. P., STORDAL, F., MARENGO, J., SILVA, T. G., DELGADO, R. C., LINDEMANN, D. S., COSTA, L. C. Mean and interannual variability of maize and soybean in Brazil under global warming conditions. **American Journal Climate Change**, New York, v. 2, n. 1, p. 237–253, 2013. https://doi.org/10.4236/ajcc.2013.24024

KILL, R. F. **Análise de metacontingências da Lei 12.608/12 que define a política nacional de Proteção e Defesa Civil**. 2016. 104 f. Dissertação (Mestrado em Ciências do Comportamento) – Curso de Pós-Graduação em Ciências do Comportamento, Universidade Federal de Brasília, Brasília, 2016.

LABAKI, L. C.; DE CASTRO FONTES, M. S. G.; BUENO-BARTHOLOMEI, C. L.; DACANAL, C. Conforto térmico em espaços públicos de passagem: estudos em ruas de pedestres no estado de São Paulo. **Ambiente Construído**, Porto Alegre, v. 12, n. 1, p. 167-183, 2012. https://doi.org/10.1590/S1678-86212012000100003

National Aeronautics and Space Administration – EOSDIS – NASA's Earth Observing System Data and Information System. Acesso em 19 janeiro de 2017. <https://reverb.echo.nasa.gov/reverb/#utf8=%E2%9C%93&spatial_map=satellite&spatial_type=rectangle>.

ROCHA, C. F. D.; BERGALLO, H. G.; ALVES, M. A. S.; SLUYS, M.V. **A biodiversidade nos grandes remanescentes florestais no Estado do Rio de Janeiro e nas restingas da Mata Atlântica**. Rima Editora, São Carlos, SP. 2003, 146p.

SELUCHI, M. E.; BEU, C. M.; ANDRADE, K. M. Characteristis of cold fronts with potential to cause heavy rainfall over the montainous region of Rio de Janeiro. **Revista Brasileira de Climatologia**, São José dos Campos, v. 18, n. 1, p. 361-376, 2016.

TRAUTENMÜLLER, J. W.; BORELLA, J.; LAMBRECHT, F. R.; VALERIUS, J.; JÚNIOR, S. C. Acúmulo de radiação solar para a produção de mudas de *cordia americana* sob diferentes manejos.**Revista Brasileira de Engenharia de Biossistemas**, Tupã, v. 10, n. 2, p. 163-169, 2016.

WILLMOT, C.J.; MATSUURA, K. Advantages of the mean absolute error (MAE) over the root mean square error (RMSE) in assessing average model performance. **Climate Research**, Hertfordshire, v. 30, p. 79-82, 2005. https://doi.org/10.3354/cr030079

WILLMOTT, C. J. On the validation of models. **Physical Geography**, Davis, v. 2, p.184-194, 1981. https://doi.org/10.1080/02723646.1981.10642213

ZOMER, R.J., TRABUCCO, A., WANG, M., LANG, R., CHEN, H., METZGER, M.J., SMAJGL, A., BECKSCHA¨FER, P., XU, J. Environmental stratification to model climatechange impacts on biodiversity and rubber production in Xishuangbanna,Yunnan, China. **Biological Conservation**, Amsterdã, v. 170, n. 1, p. 264–273, 2014.