International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:13, No:3, 2019

Uncertainty of the Brazilian Earth System Model for Solar Radiation

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***Abstract*—**This study evaluated the uncertainties involved in the solar radiation projections generated by the Brazilian Earth System Model (BESM) of the Weather and Climate Prediction Center (CPTEC) belonging to Coupled Model Intercomparison Phase 5 (CMIP5), with the aim of identifying efficiency in the projections for solar radiation of said model and in this way establish the viability of its use. Two different scenarios elaborated by Intergovernmental Panel on Climate Change (IPCC) were evaluated: RCP 4.5 (with more optimistic contour conditions) and 8.5 (with more pessimistic initial conditions). The method used to verify the accuracy of the present model was the Nash coefficient and the Statistical bias, as it better represents these atmospheric patterns. The BESM showed a tendency to overestimate the data of solar radiation projections in most regions of the state of Rio Grande do Sul and through the validation methods adopted by this study, BESM did not present a satisfactory accuracy.

***Keywords*—**Climate changes, projections, solar radiation, uncertainty.

I. Introduction

DUE to the need for an energy matrix diversification, the knowledge of solar radiation measurements associated with climate change projections becomes increasingly important. There is a series of research centers around the world that are engaged with the development and improvement of mathematic models capable to project the behavior of important variables to a renewable matrix. At the same time, the IPCC conducts researches to assess and establish links between the climate variability and the human activities, elaborating changes in the climate environment until the end of century XXI [1].

According to [2], the BESM is a set of computational programs that couple the components of superficial continental, sea, atmosphere and chemistry. It aims to generate climate changes' scenarios with the Brazilian perspective, by incorporating process of clouds formation, vegetation dynamics and the knowledge generated in Brazil about the influence of the Brazilian biomed on the global climate.

The BESM was developed in the National Institute of Space Research (INPE) and enables Brazil to join the selected group of the nations with contributions from global climate change scenarios to IPCC reports. The pioneering contribution of Brazil for the global climate change scenarios was performed with the scenarios generated by the BESM-AO 2.3 model, with participation in the project CMIP5 [2].

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II. Material and Methods

A. Study Area

The state of Rio Grande do Sul is located at the southern end of Brazil, between the latitudes of 27º and 34º South (S) and the lengths of 50º and 57º West (W) (Fig. 1). The predominant climate is subtropical, being subtropical of altitude in the region of the upper plateau.

It was used monthly solar radiation data from 13 surface meteorological stations that belong to the National Institute of Meteorology (INMET), for the period of 2006 to 2013. The choice of the stations was due to the greater availability of solar radiation data in those locations.

B. Data

In this work, monthly solar radiation series of the BESM of the CPTEC were used. The data were obtained through the WCRP (World Climate Research Programme) website, presenting a resolution of 1.85º x 1.86º latitude-length, for the period of 2006 to 2013.

The CMPIP5 that provides an infrastructure based on the diagnosis, intercomparison, documentation and data access of climate models, from different atmospheric modeling centers [3].

The phase 5 of the project (CMIP5) involves different components models (atmospherics, oceanic, sea ice, terrestrial surface, terrestrial ice, oceanic biogeochemistry, terrestrial chemistry), all following a common experimental protocol [4].

The general combined Atmosphere-ocean Circulation models can be configured in several different ways, allowing the simulated weather to adjust to the climatic forcing, with the increase of the atmospheric carbon dioxide [5].

The information is provided in grid points, and it was used the Grid Analysis and Display System (GRADS) software for the extraction of the monthly values of solar radiation, using the information in the grid where each meteorological station was used in this research. The GRADS is a system for visualization and data analysis in grid points that works with a matrix of binary data, where the variables can have four dimensions (length, latitude, vertical levels and time) [6].

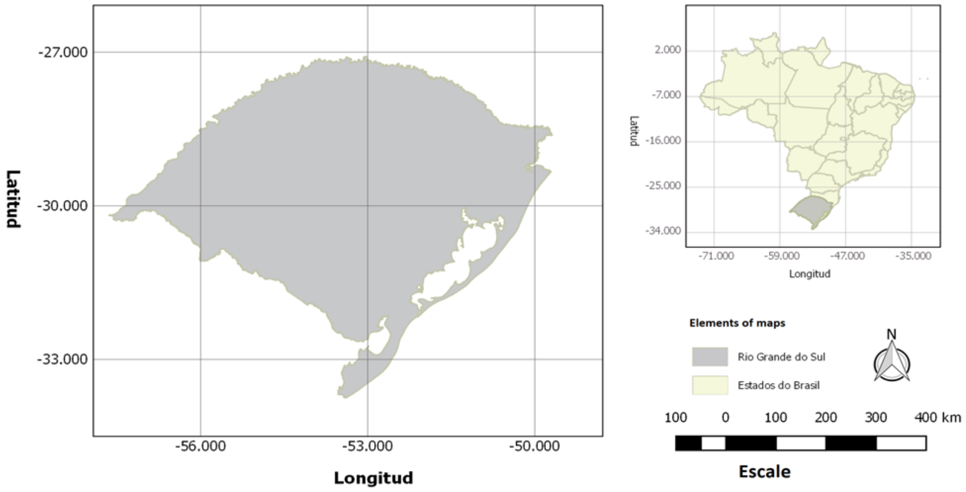

Fig. 1 Location Map of the Study Region

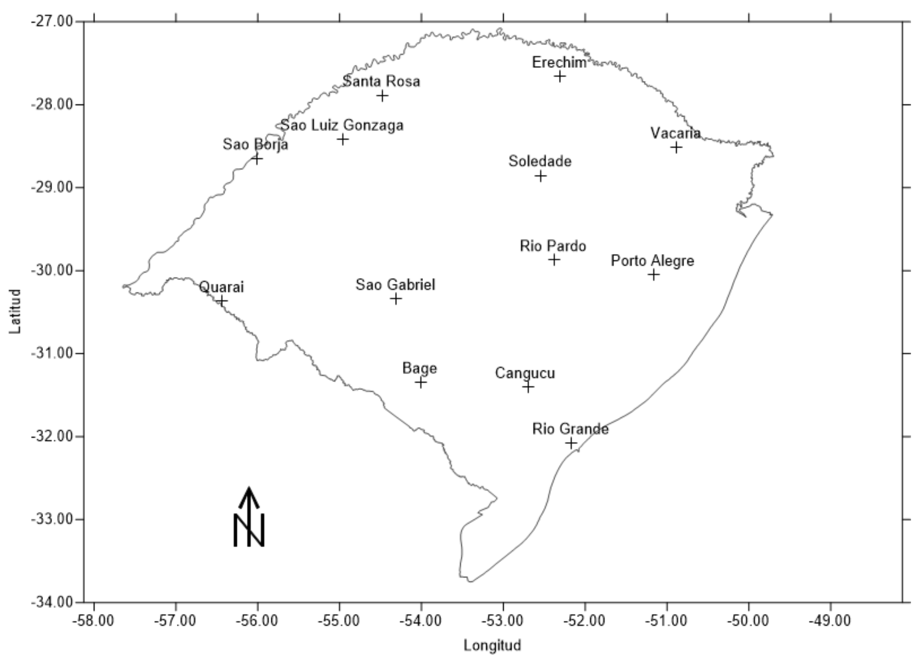

Fig. 2 Location Map of the Meteorological Station

C. Methodology Validation

The statistics used to compare the solar radiation seen with the solar radiation projections obtained through the climate models were: the bias (1), which indicates a possible tendency of the model data to overestimate or underestimate the solar radiation data, that was observed – being the ideal value the closest to zero; the efficiency coefficient (EFF) (2) that evaluate the accuracy of the alternative data, ranging from negative to 1, with the 1 being the perfect fit. For this coefficient, the methodology is considered: satisfactory if the value is between 0.50 and 0.65; good if the value is between 0.65 and 0.75; and very good if the value is above 0.75 [7].

The equations used are as follows:

$$Viés = \frac{1}{n}\sum_{1}^{n}(Y_{proj} - Y_{Obs}) \quad (1)$$

$$EFF = 1 - \frac{\sum_{1}^{n}(Y_{obs} - Y_{proj})^2}{\sum_{1}^{n}(Y_{obs} - \overline{Y_{obs}})^2} \quad (2)$$

where YOBS is the value of the data observed in the i period; YGPCP is the value of the data of GPCP for the I period; $\sigma_{GPCP}\sigma_{OBS}$ are the standard deviations of GPCP data and observed data; $\overline{Y_{GPCP}}$ is the average value of GPCP data; $\overline{Y_{OBS}}$ is the average of the observed data and n is the total number of data.

Table I shows the limits of accuracy classification, using the Nash coefficient and the percentage of bias.

TABLE I
EVALUATION OF THE BESM PERFORMANCE FROM THE NASH-SUTCLIFFE EFFICIENCY COEFFICIENTS [9]

Performance evaluation	Nash Coefficient
Very Good	0,75<EFF<1,00
Good	0,65<EFF<0,75
Satisfactory	0,50<EFF<0,65
Unsatisfactory	NSE<0,50

III. RESULTS AND DISCUSSIONS

According to Table II, where the bias of each scenario is shown in the comparison of measured data and projection data, we can verify how much the BESM tends to overestimate the observed data in the different meteorological stations in which the measurements were collected, agreeing with the results shown by [8].

TABLE II
BESM BIAS FOR SOLAR RADIATION

City	BESM	
	RCP 4.5	RCP 8.5
São Borja	0.831	0.827
Quaraí	0.838	0.830
Santa Rosa	1.096	1.114
São Luiz Gonzaga	0.758	0.758
São Gabriel	0.890	0.875
Bagé	0.551	0.559
Erechim	0.791	0.776
Soledade	0.822	0.806
Rio Pardo	1.115	1.097
Canguçu	1.192	1.174
Rio Grande	1.054	1.042
Vacaria	1.059	1.042
Porto Alegre	1.514	1.495

Analyzing Table III, it is possible to see the values of the Nash coefficient for each meteorological station. In this way, we verify that only at Bagé Station the value of EFF can be considered good (according to Table I), and in the others 12 stations the values were with the indexes considered unsatisfactory, which means that they were lower than 0.5.

TABLE III
EFFICIENCY COEFFICIENT OF BESM FOR SOLAR RADIATION

City	BESM	
	RCP 4.5	RCP 8.5
São Borja	0.339	0.321
Quaraí	0.429	0.402
Santa Rosa	0.128	0.131
São Luiz Gonzaga	0.422	0.420
São Gabriel	0.493	0.460
Bagé	0.720	0.737
Erechim	0.318	0.312
Soledade	0.383	0.385
Rio Pardo	0.086	0.049
Canguçu	0.086	0.049
Rio Grande	0.301	0.260
Vacaria	-0.123	-0.130
Porto Alegre	-0.397	-0.432

According with the comparison between the spatialization maps of the efficiency coefficients, it was verified a low index of accuracy in both scenarios for all the state of Rio Grande do Sul. For both the optimistic scenario (see Fig. 3) and the pessimistic scenario (see Fig. 4), a little exception happens in the 'pampa gaucho', where a Nash Coefficient of 0.6 is presented – which according to [9] can be considered good – and for the others regions of the state the index was considered unsatisfactory.

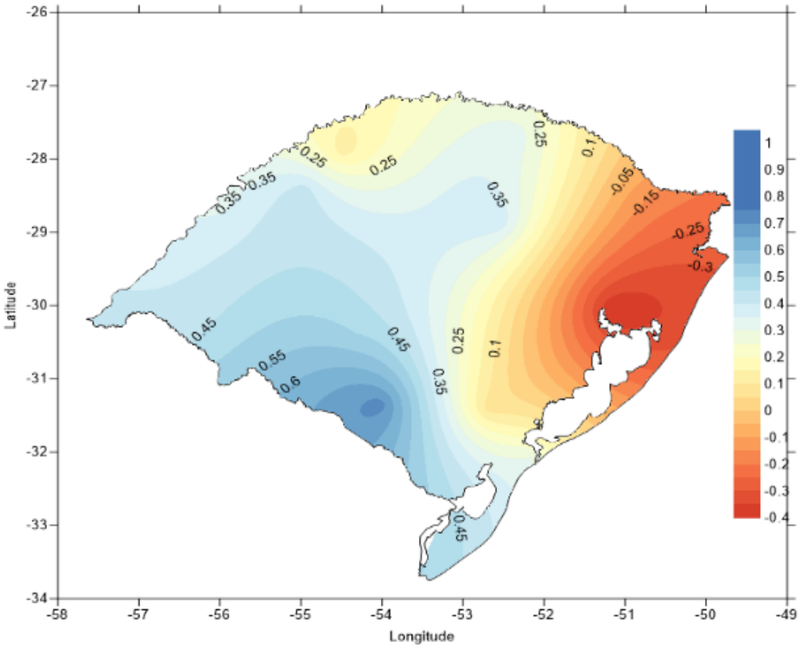

Fig. 3 Spatialization of the Efficiency Coefficients of the BESM model to RCP 4.5

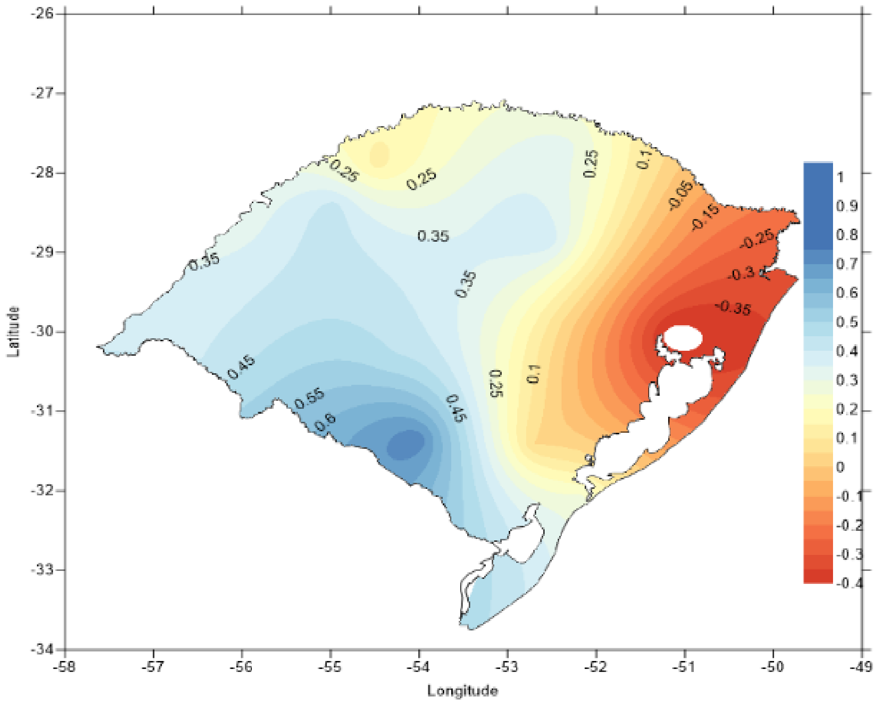

Fig. 4 Spatialization of the Efficiency Coefficients of the BESM model to RCP 8.5

IV. Conclusion

The BESM model, in general, did not represent a satisfactory spatial distribution of the month average of irradiance in the Earth's crust in the region of Rio Grande do Sul state. The comparison between the BESM projection and the observed data in the meteorological stations shows an uncertainty in these solar radiation projections.

The results of this research were for the solar radiation variable. As a possibility for future work, it is suggested an accuracy analyze for other variables projected by BESM, as the rainfall index, speed, and winds direction.

Acknowledgment

To the Weather and Climate Prediction Center and the National Institute of Meteorology, by the availability of the data used in this research.

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