Proceeding Paper

Climatic Variability of Precipitation Simulated by a Regional Dynamic Model in Tropical South America [†]

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Abstract: The present study aimed to analyze the seasonal and interannual variability of simulated rainfall over two contrasting regions of Tropical South America. Unlike several previous studies, our analyses were focused on areas with different rainfall regimes within two major regions: the Amazon Basin (AMZ) and Northeast Brazil (NEB). For this purpose, we used the RegCM4.6 climate model and performed two continuous 30-year simulations (1981–2010) with a 50 km grid spacing. In the EXP_EM simulation we used the convection parameterization of Emanuel (1991) and in the EXP_GR experiment we used Grell's parameterization (1993). Differences between simulations and observations were assessed using the Student's t-test, with a *p*-value > 0.01. The mean bias and Willmott's coefficient of agreement were calculated. Considering these metrics, the EXP_EM simulation presented an overall advantage over the EXP_GR simulation.

Keywords: Amazon Basin; Northeast Brazil; RegCM4

1. Introduction

Studies conducted from the Regional Climate Models (RCM) in South America are mostly performed with different versions of the Regional Climate Model (RegCM) [1]. A comprehensive review [2] of the main results and future perspectives of the works performed with RCM in South America were recently presented and, in this context, our motivation is the challenge of simulating the intraregional variability of rainfall in the Amazon Basin (AMZ) and in the Northeast of Brazil (NEB), since they are two important areas in Brazil through a climatic and economic perspective.

Furthermore, the climate over these regions have distinct characteristics and a remarkable variability regarding rainfall regime. Thus, the analysis of the simulated precipitation over subregions in these areas allows a broader and updated assessment of the reliability of the RegCM4 in the tropical South America.

The AMZ has a mostly humid tropical climate; while in the NEB the climate is predominantly semiarid [3], except for the eastern coastal areas and its northern portion. Regarding precipitation climatology, the AMZ can be divided into six homogeneous subregions [4]. NEB, on the other hand, is characterized by five areas with different precipitation regimes [5]. Despite these particularities, trend analyses indicate changes in climate

extreme indices both in AMZ and NEB [6], mainly for indices associated with maximum and minimum temperatures [7,8].

The objective of the present study is to analyze the spatio-temporal climate variability of two 30-year simulations (1981–2010) performed by the RegCM4 model (version 4.6) in homogeneous rainfall areas of the AMZ and the NEB.

2. Material and Methods

We use daily interpolated data in a regular grid of 25 km × 25 km covering the entire territory of Brazil [9], which were obtained from information collected by a network of rain gauges managed by different research and water resources management institutes in Brazil. These data have been used in different studies in the tropical region of South America, i.e., for the characterization of extreme indices trends on AMZ and NEB [7].

Simulations were performed with the RegCM version 4.6, which is a regional dynamic model originally developed in the late 1980s. The model went through profound transformations and improvements over time, included relatively sophisticated cloud microphysics processes [1].

We selected 11 areas (Figure 1) to evaluate the model's simulations. This selection is based on previous studies that used the multivariate cluster analysis technique based on the monthly climatological averages of accumulated precipitation in each region. In the AMZ, six homogeneous rainfall regions were defined (A1, A2, ..., A6) [4]. In the NEB, there are five homogeneous rainfall regions (N1, N2, ..., N5) [5]. The assessment of the simulations was carried out considering the daily and monthly series of the average precipitation in each area. Estimations over the ocean were excluded from the calculations because data from [9] are available only for continental regions.

In order to evaluate the simulations, statistical analyses were performed considering: Student's *t*-test for differences between simulated and observed mean values with *p*-value > 0.01; (ii) calculation of the bias for the evaluation of under- or overestimation of precipitation; (iii) calculation of the indicator of agreement (*d*), called Willmott index [10].

3. Results

The average, standard deviation and the result of the t-test for equal means are presented in Table 1. In general, the results of the simulations are statistically different from the observations. However, results were consistent regarding temporal (difference between dry and wet periods) and spatial (higher values in the AMZ if compared to the NEB) distribution. Only the EXP_EM experiment presents statistically equal means to the observations, particularly during the dry period in areas N2, N3, A2, A3 and A6. In the wet season, only simulations in areas N2 and N5 for the EXP_EM experiment were statistically equal to observations. When analyzing the average rainfall in all areas of the NEB and the AMZ one can observe that the EXP_EM experiment is able to satisfactory reproduce rainfall over the NEB both in the wet and dry seasons. The same does not occur for the AMZ, although the average values retrieved by this simulation were more similar to observations if compared to the EXP_GR experiment.

The bias and the index *d* for each area (and each season) are presented in Table 2. Rainfall is underestimated (bias < 0) in all areas of the NEB and the AMZ in the EXP_GR simulation, with areas N3 (bias = −5.08 mm/day) and A3 (bias = −8.67 mm/day) standing out. The EXP_EM experiment underestimates observed rainfall throughout all AMZ subregions during the wet season. On the other hand, it overestimates precipitation in areas N1 and N2. If we consider mean rainfall in all NEB subregions, EXP_EM overestimates observations by approximately 0.35 mm/day. A clear relationship between higher *d* index values and lower bias can be noticed. At the same time, the *d* index for the EXP_EM experiment is consistently higher than for EXP_GR, indicating that EXP_EM presents better overall results when analyzing bias and the Wilmott's coefficient.

Table 1. Average, standard deviation and the result of Student's t-test for equal means. Values in bold indicate that the numerical experiment simulation is equal to the observation with *p*-value > 0.01. Precipitation is expressed in mm/day.

Area	Wet Period			Dry Period		
	OBS	EXP_GR	EXP_EM	OBS	EXP_GR	EXP_EM
N1	4.69 (±1.38)	1.53(±0.30)	7.70(±4.07)	0.86(±0.40)	1.29(±0.14)	1.47(±0.88)
N2	**4.95(±1.61)**	2.13(±0.57)	**5.94(±2.14)**	**0.33(±0.15)**	0.16(±0.08)	**0.41(±0.40)**
N3	7.91(±1.58)	2.81(±0.94)	6.07(±1.74)	**0.77(±0.30)**	0.20(±0.12)	**0.57(±0.54)**
N4	3.84(±1.21)	1.75(±0.59)	3.58(±1.35)	0.69(±0.17)	0.25(±0.06)	0.35(±0.21)
N5	**3.39(±1.51)**	1.60(±0.68)	**3.30(±1.49)**	1.13(±0.29)	0.61(±0.12)	0.79(±0.34)
A1	10.09(±0.88)	2.93(±0.17)	3.97(±0.79)	6.39(±0.80)	2.11(±0.46)	4.27(±0.52)
A2	9.35(±1.39)	2.51(±1.04)	5.75(±1.19)	**3.60(±1.06)**	1.13(±0.38)	**3.57(±0.71)**
A3	11.05(±1.58)	1.82(±0.96)	6.65(±2.18)	**2.10(±0.60)**	0.31(±0.26)	**2.39(±1.29)**
A4	9.48(±0.94)	3.09(±0.91)	3.87(±0.53)	2.59(±0.52)	0.55(±0.21)	1.24(±0.29)
A5	9.61(±1.34)	2.80(±1.10)	5.84(±1.04)	1.24(±0.34)	0.10(±0.08)	0.77(±0.27)
A6	8.57(±1.24)	3.56(±0.79)	4.63(±0.69)	**0.77(±0.35)**	0.25(±0.12)	**0.64(±0.17)**

Table 2. Bias and the Willmott's coefficient (*d*) between simulated and observed values in the different regions of the Amazon (AMZ) and the Northeast Brazil (NEB) and in each studied period (wet and dry).

Area	Wet Period				Dry Period			
	EXP_GR		EXP_EM		EXP_GR		EXP_EM	
	Bias	*d*	**Bias**	*d*	**Bias**	*d*	**Bias**	*d*
N1	−3.06	0.16	3.05	0.51	0.47	0.23	0.64	0.51
N2	−2.78	0.28	0.98	0.67	−0.17	0.32	0.09	0.50
N3	−5.08	0.29	−1.81	0.62	−0.56	0.26	−0.18	0.47
N4	−2.09	0.53	−0.25	0.72	−0.44	0.20	−0.34	0.41
N5	−1.96	0.59	−0.23	0.83	−0.51	0.39	−0.32	0.68
A1	−6.75	0.23	−5.21	0.30	−4.26	0.25	−2.42	0.34
A2	−6.76	0.18	−3.41	0.36	−2.43	0.32	−0.36	0.47
A3	−8.67	0.21	−4.12	0.42	−1.81	0.20	0.13	0.50
A4	−6.53	0.22	−5.62	0.19	−2.00	0.17	−1.33	0.57
A5	−7.03	0.25	−3.55	0.36	−1.15	0.20	−0.47	0.36
A6	−5.17	0.32	−3.87	0.35	−0.52	0.30	−0.15	0.38

4. Discussion

Regarding precipitation rates, the results of our experiments are consistent with the literature cited in Table 3, indicating an underestimation of precipitation during the wet and dry season in the AMZ. Previous studies indicated underestimations in the NEB during both seasons, which is consistent with the results retrieved with the Grell's parameterization (REG_GR experiment) [11,12]. Simulations with the REG_EM experiment largely agree with multiple simulations carried out in South America [13], which reported overestimations of rainfall during the wet season and underestimations during the dry season.

Another strength of the REG_EM experiment in the NEB is observed by analyzing the coefficient *d*, which was higher in the present study if compared to those reported by [13]. These authors argued that the results retrieved using multiple models could have been influenced by the effect of the domain size in the NEB region. Therefore, the choice of a domain that contemplates a larger part of the Tropical Atlantic basin may have positively influenced the simulations. This hypothesis is consistent with other studies (e.g., [14,15]), which reported that precipitating systems that act in the eastern coast of Brazil

originate at the South Tropical Atlantic, typically assuming the characteristics of easterly waves disturbances.

5. Conclusions

The purpose of this research was to perform an objective evaluation of precipitation simulated by two 30-year experiments (1981–2010) performed with the RegCM4.6 model on the tropical region of South America. Our focus was to analyze results over subregions in the AMZ and the NEB, which are contrasting regions regarding climatic characteristics: precipitation in the AMZ is higher than in the NEB. A dry bias was observed over almost the entire AMZ region and a wet bias was observed over the N1 region in the NEB, which is closer to the zone of influence of the ITCZ. The simulation performed using Emanuel's parameterization presented advantages over the Grell's parameterization experiment regarding precipitation rates and variability.

Regardless of the experiment, simulations were less accurate in the AMZ, especially in the Equatorial region. In the NEB, the model showed good agreement with observations, especially in regions closer to subtropical latitudes (N4 and N5). The simulations were able to reproduce the interannual variability of precipitation, with droughts associated with the occurrence of hot phases of the El Niño Southern Oscillation and with the interhemispheric gradient in the Tropical Atlantic pointing to the north.

The EXP_EM experiment also seems to retrieve better results if compared to findings reported in previous studies, especially those that used Grell's parameterization, such as studies developed in the context of the CLARIS-LPB project. Thus, our results indicate that the use of Emanuel's parameterization in long-term simulation studies over the AMZ and the NEB may be beneficial and improve results.

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