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Simulations of meteorological fields in the Amazon and Northeast Brazilian in the fall in an El Niño year

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ABSTRACT

The warming in the Tropical Pacific Ocean causes changes in the large-scale circulation of the atmosphere, causing climatic anomalies in several regions of the globe. Thus, several sensitivity tests have been used in regional climate models with the aim of improving the representativeness these models. This study aimed to compare two sets of simulations with the same parameterization, one with a grid spacing of 50 km and the other of 25 km, in addition to evaluating the performance of the simulations of different spatial resolutions with large-scale data from the ERA-Interim. It was analyzed the average of the four synoptic timetables of the near-surface temperature, divergence, vorticity, vertical velocity, wind speed and direction, and the average of the total precipitation of 00UTC. It is to compare with the data of the TRMM satellite at the same time, both in Amazon region and in the Brazilian Northeast (NEB), in the fall of a year of intense El Niño. The simulations were carried out with the version 4 of the Regional Model RegCM for May 1998. The parameterization of convective cumulus best represents the phenomena in the Amazon region, and for the Northeast, Brazilian is the of Grell in May. It is always necessary knowledge about the physics model can describe the phenomena of interest before applying improvement methods.

Keywords: Model, grid spacing, resolution.

Introduction

A phenomenon that interferes in the climatic characteristics of this large-scale circulation of the Earth's atmosphere is the phenomenon El Niño Southern Oscillation (ENSO) (Alves, 1992). Apparently, the sea level pressure difference (PNM) between the east-central (Tahiti) and western (Darwin) sectors in the Tropical Pacific Ocean is related to an anomalous warming of generally cold waters on the east side of the ocean. This warming causes changes in the large-scale circulation of the atmosphere, causing climatic anomalies in various regions of the globe.

Increasingly regional climate models are being used through different methodologies to implement improvements in the predictions of daily rainfall intensity in the tropical region of South America, as can be seen in Silva (2016). Several sensitivity tests with higher resolutions, with the purpose of representing adequate meteorological phenomena using the model, portrayed, being an important regional model, which belongs to the International Center Theoretical Physics (ICTP). Due to the contribution of many researchers to RegCM, there were six versions: RegCM1, RegCM2, RegCM2.5, RegCM3, RegCM4, and RegCM4.1, but with the refinement of RegCM it was currently developed and has already been used the non-hydrostatic version 4.6 that is stable. The same is still widely used because it is public and has open source code. It has an excellent computational performance, according to Silva & Silva (2014).

The study aimed to compare and evaluate the performance of two sets of simulations of the regional climate model of distinct spatial resolutions with large-scale data from the ERA-Interim and the 00Z TRMM satellite data only for precipitation in a region of the Amazon and the Brazilian Northeast in the fall of a year of intense El Niño. It permits to investigate the improvement of the quality of the simulations by reducing the grid spacing so that the simulations performed by the model used can be forced to the "ideal" for knowing the skill and systematic errors.

Material and Methods

Two boxes were selected, the Brazilian Northeast region (NEB) and a region of the Amazon, because this period corresponds to the end of the rainy season within the NEB and the beginning of the rainy season on the coast of the same region. It is worth emphasize that because it is an atypical year due to intense El Niño, the total precipitation recorded is generally below the average for what was expected during this period, it also occurs in the Amazon region in these conditions of the El Niño Southern Oscillation (ENSO) phase. The coordinates referring to the NEB and Amazon boxes are, respectively: -1N -19S -48W -35E and 3N -14S -70W -50E, based on Silva & Silva (2014).

According to Reboita (2008), the RegCM is a limited area model, hydrostatic, compressible, of primitive equations and in sigma vertical coordinate. The equations are discretized in the model using the finite difference method in Arakawa-Lambis B-grid. The RegCM4 also had an algorithm to reduce horizontal diffusion in the presence of extreme topography gradients. Moreover, for application in climate studies, several physical parameterizations have been incorporated into RegCM throughout its versions.

Related to parameterization of the experiment configuration, RegCM4 considers two schemes for the treatment of humid processes in the atmosphere: one for convection in deep cumulus (on a subgrade scale) and the other for precipitation that is solved at the grid scale, being that the cumulus schemes available in RegCM4 are: Grell (1993) with the Fritsch-Chappell (GFC) and Arakawa-Schubert (GAS) closures, Anthes-Kuo (Anthes, 1977), and MIT-Emanuel (Massachusetts Institute of Technology-Emanuel) (Emanuel, 1991).

After the simulations it were calculated the average for both analyzed boxes of the near-surface temperature, the total precipitation, the divergence at 200 hPa and the vorticity at 850 hPa were calculated using the zonal and meridional components of the wind, the vertical velocity at 500 hPa, wind speed and direction also at 850 hPa for May 1998 (year of intense El Niño and transition to La Niña). The numerical experiments were performed using version 4 of the RegCM (Regional Climate Model) regional model with the contour conditions of the terrain, sea surface temperature (SST), and large-scale atmospheric conditions of the NCEP. It was an initial condition for the simulated period with parameterization of Cumulus Convection (Rain) of Emanuel and Grell with closure Arakawa-Schubert. Later it was used contour conditions of the terrain, the SST and the state of the atmosphere of the ERA-Interim (Reanalysis of European Centre for Medium-range Weather Forecasts-ECMWF), with parameterization of Emanuel and Grell and Arakawa-Schubert closure, respectively. The RegCM4 solved the first set of simulations with a grid spacing of 50 km and the second with 25 km from the respective physical options, totaling eight experiments.

The second round of simulations, aiming to increase the spatial resolution, was made reducing the grid spacing from 50 km to 25 km, to change the terrain contour condition from 60 to 5 to execute the new round of simulations normally. It considered the vegetation map for the resolution of interest is different from that used in the previous set of simulations, which caused an extended period to simulate this set due to computational cost, requiring a larger number of processors. Also, to maintain the spatial domain of the simulations, the number of points in x and y were doubled, and the computational stability criterion was checked.

The simulations were compared with TRMM (Tropical Rainfall Measuring Mission) satellite data in the analysis of the total precipitation at 00UTC, as well as ERA-Interim reanalysis data since in the absence of observed surface (*in situ*) data for all the analyzed variables preferred to use data from the ERA-Interim. It was chosen to convert the data of the average of the near-surface temperature of the scale of Kelvin to Celsius. The analysis of the vertical velocity average at 500 hPa, considering that this level corresponds to the non-divergent level, where it is the maximum vertical velocity and the analysis of the divergence at 200 hPa given that high-level defluence is indicative of surface mass convergence. It is expected that the convergence in the upper troposphere will subsidize movements at low levels, while the analysis of the 850 hPa vorticity field depicts cyclonic movements and the analysis of the average velocity and direction of the wind near the surface in this period was mainly due to the climatological average position of the Intertropical Convergence Zone (ITCZ), related to the intensity and confluence of the trade winds in surface influencing both regions during this period of the year.

It was preferred to use the average of the total precipitation instead of the accumulated, which is better to observe the behavior of said variable, but when plotting the accumulated obtained very high values due to the presence of noises that persisted with the adjustment of the scale of values. The average was extracted of the total simulated precipitation was 00UTC since the TRMM data were provided only for this time. Subsequently, the average of the boxes corresponding to a region of Amazonia and the Northeast Brazilian of the total precipitation of UTC to compare with the data estimated indirectly by the reflectivity of radar hydrometeors that was aboard the meteorological satellite of equatorial orbit TRMM, as well as were extracted the data concerning the average of the boxes study of the other variables analyzed under the conditions described previously.

The study aimed to analyse methods of evaluation the simulations comparing the data close to the observed and applied using the software R to perform calculations of the difference between the simulated and the observed (residuals), and consequently to verify the overestimation and underestimation of the model, in addition to the calculation of the descriptive statistics. A script in GrADS (file.gs) was also used to extract the mean of the selected boxes from TRMM, ERA-Interim, and the two sets of simulations.

It was used the software GrADS (Grid Analysis and Display System) as a tool for generation and visualization of the simulations through of the analysis of the average of the six meteorological variables mentioned with the desired conditions.

Results

Subjective analysis

Firstly, the simulations were evaluated subjectively only using the analysis of the meteorological fields mentioned confronting with data close to the observation (Figura 1).

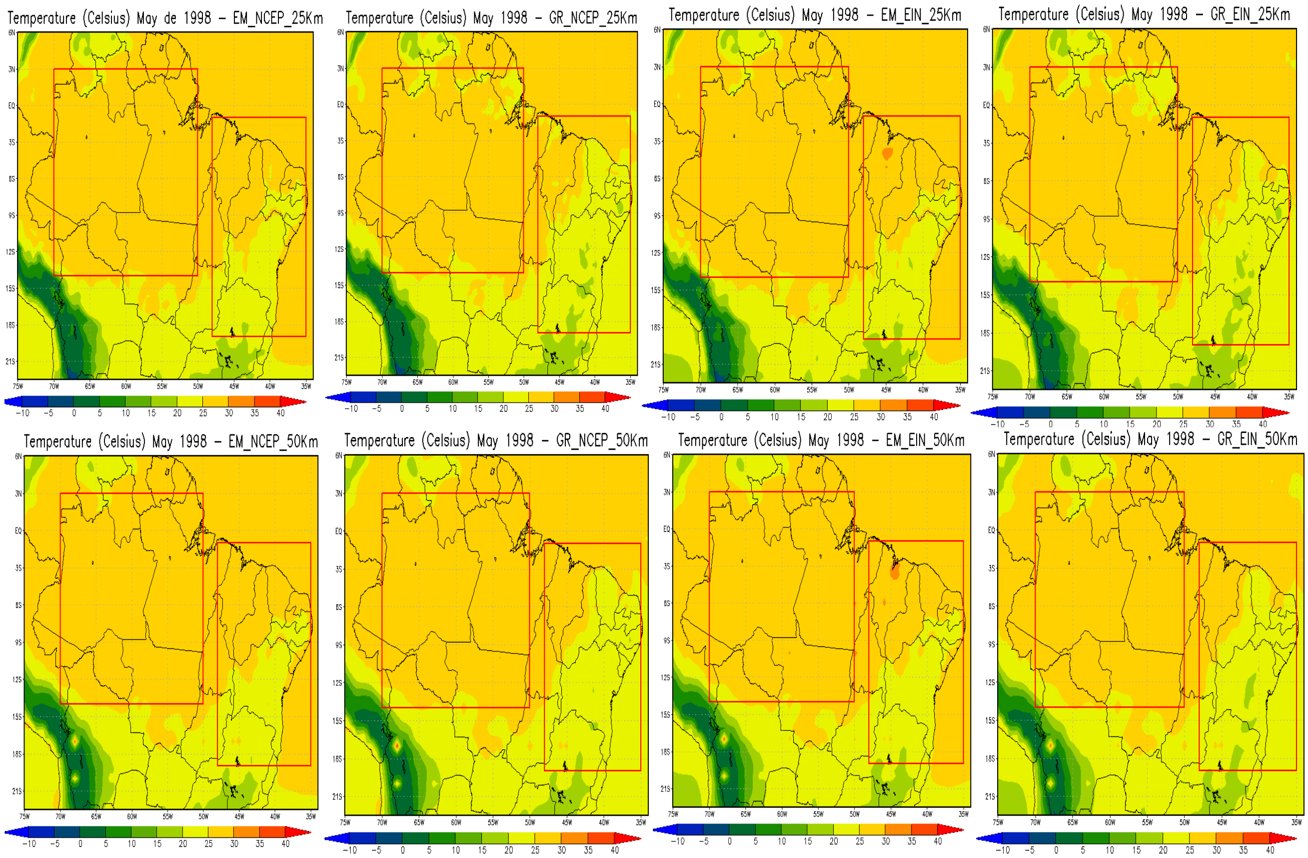

Figure 1. Average of the near surface temperature of the 25 km and 50 km simulations set for May 1998 (Lucas, 2017).

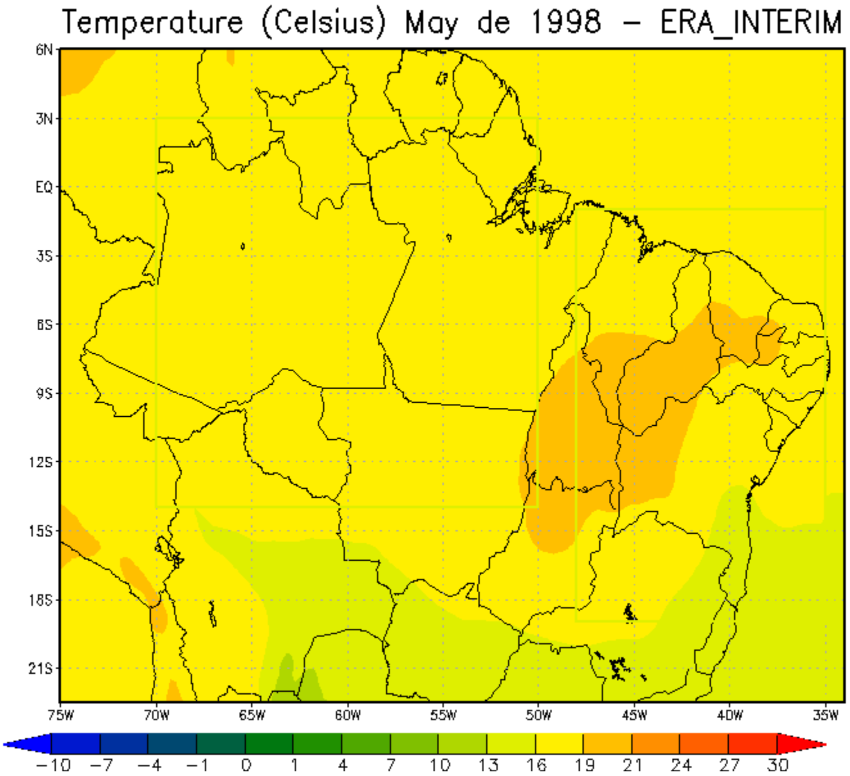

Figure 2. Average near surface temperature for May 1998 of ERA-Interim data (Lucas, 2017).

The Figures 1 and 2 show that the analysis of both sets of simulations through the average of the near surface temperature allows checking that the set of simulations of 25 km better evidence the average temperature behavior during this period. Through the spatial resolution, it is possible to check with more precision variations in the space of said variable in specific points compared to the domain covered, probably associated with the topography of the surroundings of these points that can be observed on smaller scales. Related to the physical options, it is noted that the Grell cumulus convection parameterization for both contour conditions and applied spatial resolutions present average temperature values relatively low practically throughout the NEB, including the Semiarid, which does not occur, since the Emanuel parameterization represents more appropriately, being even better when simulated with grid spacing of 25 km and with contour conditions of the ERA-Interim, but when compared to the ERA-Interim reanalysis data the two sets of simulations overestimate, however, it is important to emphasize that the reanalysis data does not equate to observation, it is an approximation of observation through assimilation of satellite data, surface stations, among other databases using the method of 4- DVAR.

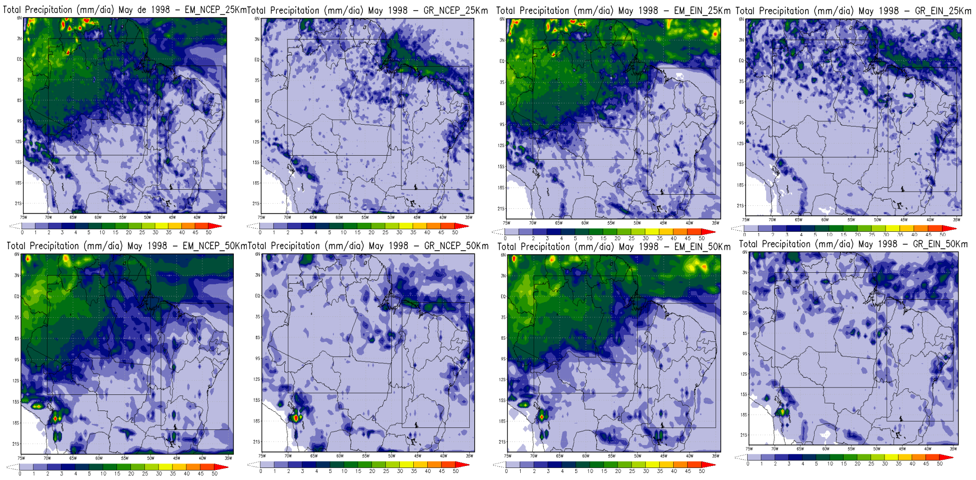

Figure 3. Average of the total precipitation of the 25 km and 50 km simulations set for May 1998 (Lucas, 2017).

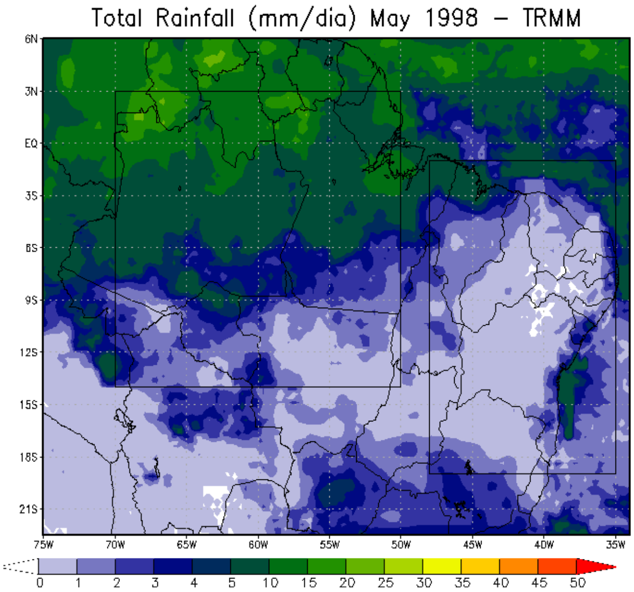

Figure 4. Average of the total precipitation from 00UTC to May 1998 of the TRMM satellite data (Lucas, 2017).

The Figures 3 and 4 show the set of 25 km simulations representation the highest average precipitation total compared to the 50 km set for all parametrizations, as can be verified in the 25 km simulations with Grell parameterization for both the the NCEP (National Centers for Environmental Prediction) contour condition and ERA-Interim in the north and east of the NEB, as well as observed in the 25 km simulations with Emanuel parameterization in both contour conditions in most of the Amazon region, being the simulation with contour condition of the ERA-Interim the most humid. Although satellite data generally overestimate precipitation because it is an indirect estimate, as is the case of the TRMM data, in short, the simulations are close to these data, and the simulations with Emanuel parameterization are adequate to the recorded average precipitation total in the Amazon in this period, and the simulations with Grell parameterization best represent the NEB box.

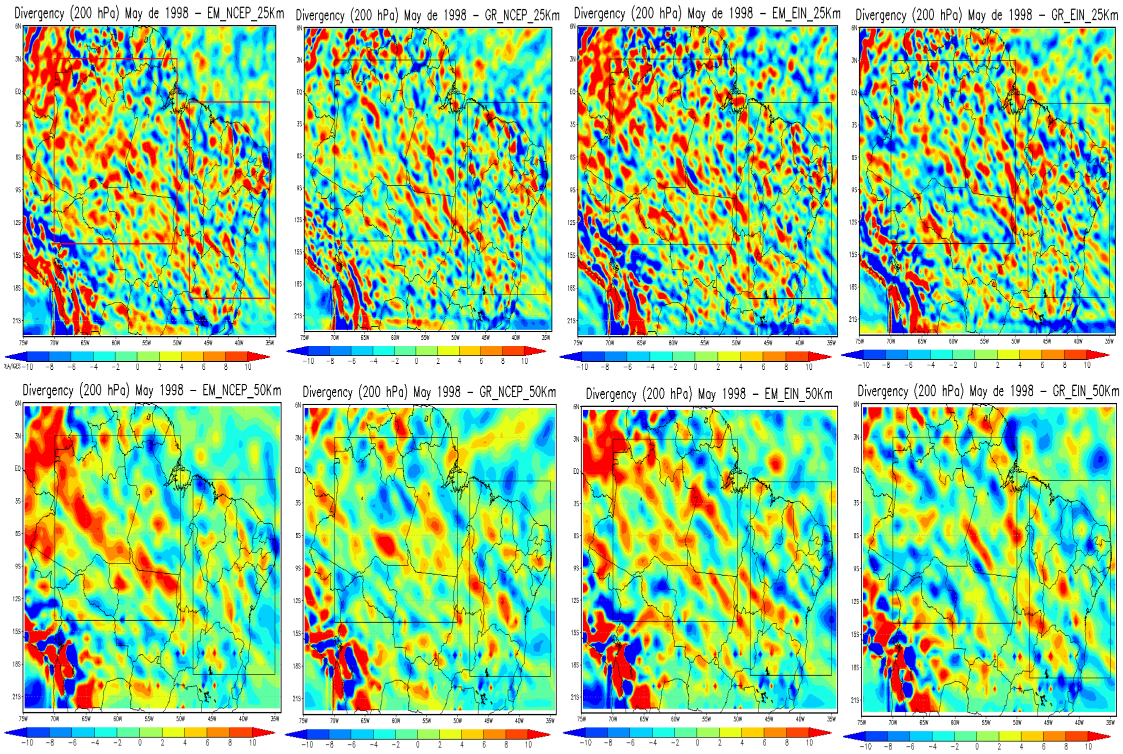

Figure 5. Average of the divergence in 200 hPa of the 25 km and 50 km simulations set by May 1998 (Lucas, 2017).

Based on Figures 5 and 6, evidently, the set of 25 km simulations represent punctually phenomena that occur on a smaller spatial scale, as can be seen in the analysis of the divergence field in 200 hPa, and for the Amazon region the simulations with Emanuel parameterization are more adequate when compared to the divergence in 200 hPa calculated with the zonal and meridional components of the wind ERA-Interim, where on average a great defluence was observed at high levels in almost all areas of Amazonia, which certainly influenced the highest mean values of total rainfall over the same region in May 1998, whereas in the NEB the simulations that most effectively explain the mean confluence in the upper troposphere over the region are merely those with Grell parameterization, happened for the total precipitation, this can occur since the divergence is predictor of rainfall.

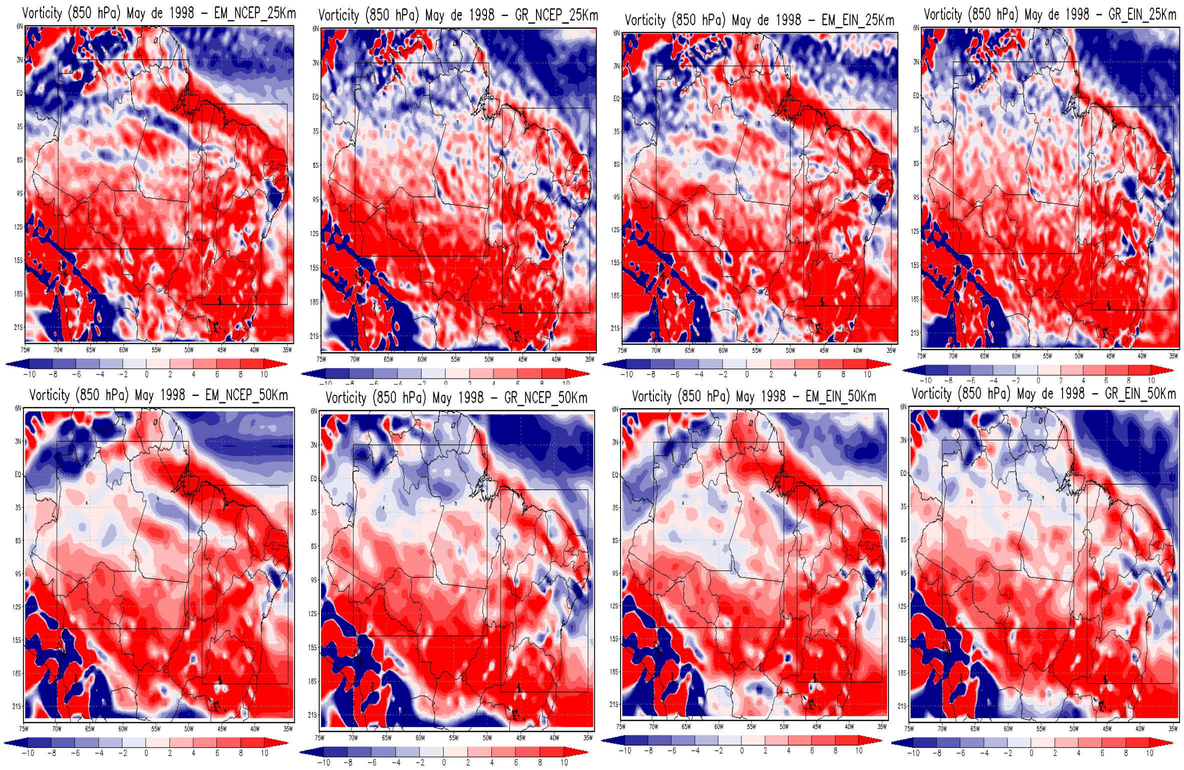

Figure 7. Average of vorticity at 850 hPa of the 25 km and 50 km simulations set by May 1998 (Lucas, 2017).

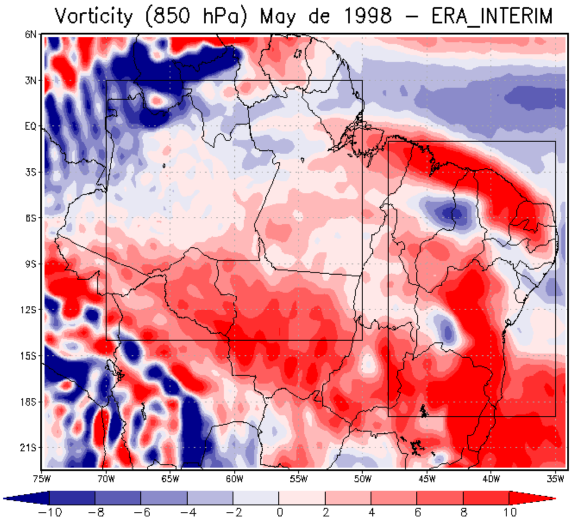

Figure 8. Average of vorticity at 850 hPa for May 1998 from ERA-Interim data (Lucas, 2017).

According to Figures 7 and 8, contrary to what was observed for the divergence in 200 hPa in the field shown above, it is verified that in the Amazon region the simulations that conveniently represent the condition close to the observation are those with parameterization of Grell and contour conditions of the ERA-Interim with both a 50-km grid spacing and a 25-km grid spacing in relation to a large average cyclonic movement in May 1998 north of the Amazon area. Negative vorticity was observed in the NEB east, southern Bahia and the central-north of Maranhão and Piauí, reflecting in average cyclonic movements during this period at the surface in the mentioned regions, where the satisfactory simulations for these conditions in the region were with the Grell parameterization of 25 km for the two contour conditions applied.

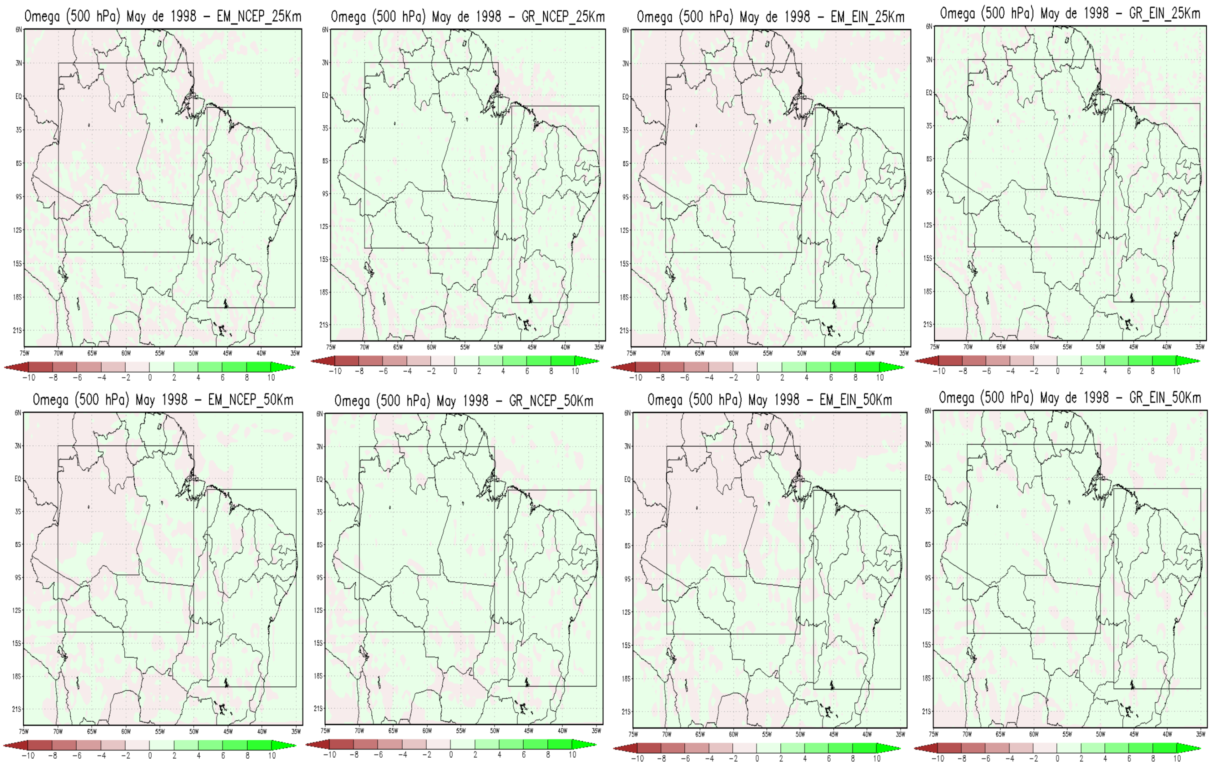

Figure 9. Average vertical velocity at 500 hPa of the 25 km and 50 km simulations set for May 1998 (Lucas, 2017).

Based on Figures 9 and 10 for the vertical velocity at 500 hPa the simulations that best portray the average conditions of upward movements shown on the basis of the omega data at the same level of the ERA-Interim in the box referring to the Amazon region are those with Emanuel convection parameterization and ERA-Interim contour condition of the 25 km and 50 km set, and in the NEB equivalent box are the simulations with Grell parameterization and with both contour conditions only the set of 25 km numerical experiments, because they are the ones that configure more intense vertical velocities in the NEB North, as it can be analyzed in the data of reanalysis for the mentioned region.

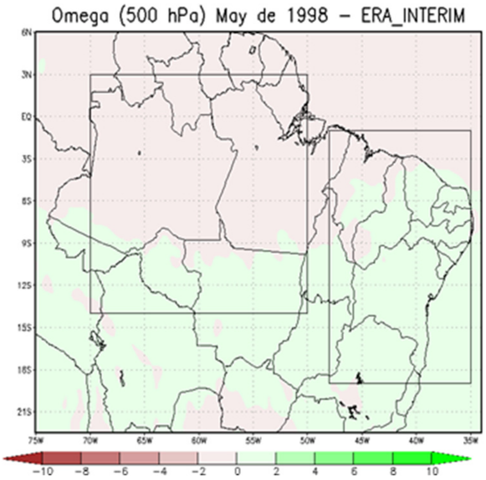

Figure 10. Average vertical velocity at 500 hPa for May 1998 from the ERA-Interim data (Lucas, 2017).

Finally, as shown in Figures 11 and 12, it can be seen that for the average wind direction near the surface in the analyzed period the simulations that express the east flow that caused a certain defluence in the center in the Amazon area are the simulations with parameterization of Emanuel and NCEP contour condition with grid spacing of 25 km and 50 km. Moreover, for the NEB are all simulations with Emanuel parameterization in common, since they describe the southeast trade and the center of the South Atlantic Subtropical High on the ocean found in the reanalysis data, different from what was observed in the simulations with Grell parameterization. Moreover, concerning the surface wind intensity, simulations with Emanuel's cumulus convection parameterization again are the ones that also best characterize the ITCZ performance in both regions studied compared to the ERA-Interim data, since simulations with Grell's physical option underestimate the average wind speed at 850 hPa in that period.

Objective Analysis

Simulations were evaluated through an analysis was carried out using the calculation of the residues and the average for May 1998 of both sets of simulations for each physical option and the data close to observation, according to Tables 1, 2, 3 and 4.

Table 1. Average and residuals of the 50 km and 25 km simulations sets with Emanuel parameterization and NCEP contour condition compared to the observed (Lucas, 2017).

Experiment	**Simulation 50 km**	**Simulation 25 km**	**Observed**	**Residues 50 km**	**Residues 25 km**
TPRAM_NCEP_EM	5,42	5,77	6,02	-0,59	-0,25
TPRNEB_NCEP_EM	1,83	2,14	1,69	0,14	0,45
DIVAM_NCEP_EM	1,70E-006	1,95E-006	1,14E-006	5,62E-007	8,08E-007
DIVNEB_NCEP_EM	-6,34E-007	-2,80E-007	-6,94E-007	5,96E-008	4,13E-007
TEMPAM_NCEP_EM	27,61	27,43	25,70	1,90	1,72
TEMPNEB_NCEP_EM	25,78	25,66	27,11	-1,33	-1,45
VORTAM_NCEP_EM	4,12E-006	4,71E-006	2,90E-006	0,000001223	0,000001813
VORTNEB_NCEP_EM	7,29E-006	7,27E-006	5,45E-006	1,83E-006	1,82E-006
WAM_NCEP_EM	-7,23E-006	-1,12E-005	-0,019	0,019	0,019
WNEB_NCEP_EM	1,49E-005	1,50E-005	0,0077	-0,0077	-0,0077
WSAM_NCEP_EM	7,09	6,92	6,04	1,05	0,88
WSNEB_NCEP_EM	6,91	6,68	6,87	0,04	-0,18

Table 2. Average and residuals of the 50 km and 25 km simulations sets with Grell parameterization and NCEP contour condition compared to the observed (Lucas, 2017).

Experiment	**Simulation 50 km**	**Simulation 25 km**	**Observed**	**Residues 50 km**	**Residues 25 km**
TPRAM_NCEP_GR	0,69	0,78	6,02	-5,32	-5,23
TPRNEB_NCEP_GR	1,08	1,37	1,69	-0,61	-0,31
DIVAM_NCEP_GR	3,33E-008	3,911E-007	1,14E-006	-1,10E-006	-7,50E-007
DIVNEB_NCEP_GR	-5,50E-007	-4,62E-007	-6,94E-007	1,44E-007	2,32E-007
TEMPAM_NCEP_GR	27,16	26,49	25,70	1,45	0,78
TEMPNEB_NCEP_GR	23,74	23,54	27,11	-3,37	-3,57
VORTAM_NCEP_GR	4,31E-006	4,75E-006	2,90E-006	1,41E-006	1,84E-006
VORTNEB_NCEP_GR	3,75E-006	4,07E-006	5,45E-006	-1,70E-006	-1,38E-006
WAM_NCEP_GR	1,92E-005	1,99E-005	-0,01	0,019	0,019
WNEB_NCEP_GR	0,00001352	1,30E-005	0,007	-0,007	-0,007
WSAM_NCEP_GR	5,10	4,83	6,04	-0,933	-1,202
WSNEB_NCEP_GR	5,26	5,13	6,87	-1,609	-1,738

Table 3. Average and residuals of the 50 km and 25 km simulations sets with Emanuel parameterization and EIN contour condition compared to the observed (Lucas, 2017).

Experiment	**Simulation 50 km**	**Simulation 25 km**	**Observed**	**Residues 50 km**	**Residues 25 km**
TPRAM_EIN_EM	6,28	6,43	6,02	0,26	0,40
TPRNEB_EIN_EM	1,13	1,26	1,69	-0,55	-0,43

DIVAM_EIN_EM	1,34E-006	1,70E-006	1,14E-006	2,03E-007	0,0000005
DIVNEB_EIN_EM	-5,58E-007	-3,12E-007	-6,94E-007	1,35E-007	3,82E-007
TEMPAM_EIN_EM	27,81	27,57	25,70	2,107	1,86
TEMPNEB_EIN_EM	25,83	25,76	27,11	-1,28	-1,34
VORTAM_EIN_EM	3,33E-006	3,92E-006	2,90E-006	4,32E-007	0,000001
VORTNEB_EIN_EM	6,70E-006	0,000006	5,45E-006	1,25E-006	1,21E-006
WAM_EIN_EM	-1,56E-005	-1,84E-005	-0,01	0,01	0,01
WNEB_EIN_EM	1,78E-005	1,84E-005	0,007	-0,007	-0,007
WSAM_EIN_EM	6,75	6,53	6,04	0,71	0,49
WSNEB_EIN_EM	6,79	6,57	6,87	-0,08	-0,29

Table 4. Average and residuals of the 50 km and 25 km simulations sets with Grell parameterization and EIN contour condition compared to the observed (Lucas, 2017).

Experiment	**Simulation 50 km**	**Simulation 25 km**	**Observed**	**Residues 50 km**	**Residues 25 km**
TPRAM_EIN_GR	0,98	1,08	6,02	-5,03	-4,93
TPRNEB_EIN_GR	0,93	1,11	1,69	-0,76	-0,58
DIVAM_EIN_GR	-0,0000004	-3,19E-007	1,14E-006	-1,55E-006	-1,46E-006
DIVNEB_EIN_GR	-6,88E-007	-4,19E-007	-6,94E-007	5,61E-009	2,75E-007
TEMPAM_EIN_GR	26,80	26,39	25,70	1,09	0,68
TEMPNEB_EIN_GR	23,75	23,63	27,11	-3,36	-3,48
VORTAM_EIN_GR	3,86E-006	4,22E-006	2,90E-006	9,56E-007	1,31E-006
VORTNEB_EIN_GR	3,96E-006	4,16E-006	5,45E-006	-1,48E-006	-1,29E-006
WAM_EIN_GR	1,77E-005	1,75E-005	-0,01	0,01	0,01
WNEB_EIN_GR	1,72E-005	1,56E-005	0,007	-0,007	-0,007
WSAM_EIN_GR	5,07	4,79	6,04	-0,96	-1,24
WSNEB_EIN_GR	5,21	5,15	6,87	-1,65	-1,71

The Tables showing the residuals (difference between the simulated and the observed), the skill of the model used was verified based on the simulations performed, where the best performance of said regional climate model will not necessarily improve with increasing spatial resolution, because the smaller residuals were observed in both sets of simulations with different grid spacing, in accordance with the physical option applied in the regions of interest and with the variables by which the simulations were analyzed in the period investigated.

Discussion

The model is of mesoscale and the version used was a hydrostatic, then several terms are despised in the vertical component. Some variables probably were due to the fact that it does not use the physics properly that the model represents. It is known that exist variations vertically of turbulence, advection, among other physical processes, and the physics of this model is correct. When performing simulations with resolutions that represent processes out of range of the model, the reduction of grid spacing will not always be the adequate solution. It is in accordance with the systematic errors in the regional models, including RegCM in different regions, mainly in the tropical region, especially in convective cumulus and precipitation parameterization in grid scale as obtained by Silva & Silva (2014).

Conclusion

The parameterization of convective cumulus which best represents the phenomena in the Amazon region is the Emanuel, and for the Northeast, Brazilian is the of Grell in May. It does not mean that in different periods the same occurs. It is always necessary to know if the model physics is able of describing the phenomena of interest before apply methods of improving the quality the simulations of any numerical models.

Considering South America, and consequently, Brazil, it is necessary additional studies to improve the technical and regional treatment of models. It is suggested to interpolate and perform the point-to-point statistics.

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