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Evaluation of the performance of a regional climate model to simulate West Africa climates: Case RegCM3 model

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Abstract: The objective of this study is to evaluate the performance of the regional climate model RegCM3 to simulate the climate parameters such as temperature and rainfall in West Africa from the perspective of climate prediction . Based on physiographic and weather data (EH5OM and EHA1B) include several variables (temperature, pressure, humidity , and fields of horizontal and vertical wind) from the mainland and maritime party. The simulation was carried out in 1991-2000 in order to facilitate comparison between model outputs and parameters observed over the same period . The application of statistical methods can show that the model overestimates in most cases the climatic parameters in West Africa. Indeed, the average error due to climate model in the temperature estimate is 2.53% in the Sahel and 2.17% in the Gulf of Guinea . As for rainfall , they are simulated by the model with relatively large mean errors . Indeed , the comparison of observed precipitation (CRU) and those simulated by the model gives average errors ranging from 8.5% in Guinean zone and 48.9% in the Sahel. The results invite to consider more observation data in the realization of different scenarios of emissions in Africa.

Introduction

Climate change has caused the rupture of the global climate balance and regional climates. They became thus a daily threat to the planet for their immediate and lasting repercussions on the environment. Their effects on global warming, which increased by 0.74 ° C between 1906 and 2005 (IPCC, 2008), the reduction in agricultural production, food security deterioration, increased incidence of floods and of drought, the spread of disease and increased risk of conflict due to the scarcity of land and water as well as the advanced sea on land due to the melting of the ice caps [1]. These climates changes directly threaten human life. Indeed, in summer 2003 in Europe, the heat wave related to the heat wave killed nearly 30,000 people, including 14,082 in France, 7,000 in Germany, 4,000 in Italy and 2,045 in Great Britain [2].

Given the extent of the damage, the issues of climate change are placed at the center of the concerns of scientists. Therefore, several climate models have been developed to explore, most of the time the future climate in different regions of the globe. These are global and regional model. The second types of models perform better than the first because they perform the simulation at high resolution by integrating both the surface conditions of climate parameters. Despite scientific progress, anomalies exit between the observed and simulated values . It is for this reason that we are testing the outputs of climate models RegCM3 with climatic data with a view to make corrections using operating methods of model outputs [3].

1. Description of the regional climate model RegCM3

The climate model RegCM3 (Regional Climate Model version 3) [4] is a regional climate model. It was set up by the International Centre for Theoretical Physics known of ICTP [5]. It is a model that is capable of multiple sockets; that is to say, from a broader area with large mesh to achieve a smaller area with smaller mesh size of about 2 km. It is written in FORTRAN language and built on a set of parameterizations of physical processes (radiation, rainfall, land use) related to each other.

It has three components which are preprocessing, processing and finally the post-processing data. Preprocessing consists of preparation input data and file entries. The treatment is the simulation itself. The post-preprocessing includes programs to convert binary results into usable formats by Ferret software.

Due to the large number of users in the world, it has been validated and reviewed extensively in various conditions, including in the US, Europe, East Asia and even Africa [4].

2. Model Inputs

2.1. Choice of emission scenario

Among families of emission scenarios, A1B and A2 scenarios are more realistic. However, our choice fell on the A1B scenario, because it is more

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accessible and is probably the best developed [6]. It explores a future in which the whole world adopts a similar economic development to the newly industrialized countries such as South Korea, whose economy is liberal and who presented continuous innovation, a stable political and social climate, all associated with rapid demographic.

2.2. Physiographic data of the study area

The regional climate model has a physiographic database of the world. From this database, are from the physical characteristics of the modeled area. These are the topographic data (altitude, slope) and the land use of the study area.

Vegetation provided by the Global Land Cover Characterization (GLCC) database gives a very different distribution from that observed in West Africa (Fig. 1A). It has been modified on the basis of major vegetation types (forest, savannah, desert, etc.) of the zone (Fig. 1B) from a file named "land use. "

Topography data is provided by the United State Geological Survey (USGS) database. Both databases are provided at a spatial resolution of 10 minutes (18.33 meters). These parameters are involved in energy exchanges, **amount of movement** and water vapor occurring at the land-atmosphere.

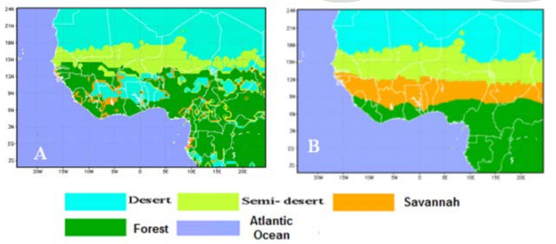

Fig. 1: Modeled domain vegetation (A: vegetation provided by the GLCC database; B: modified vegetation and used in the model)

3. Climate Data

3.1. Initial conditions

The RegCM3 model uses data to initialize the calculations. These meteorological data and EH5OM EHA1B which respectively include the thermodynamic and dynamic variables (temperature, pressure , humidity, and the fields of horizontal and vertical wind) from the mainland and Sea Surface Temperature (SST) data. These data are provided by global climate model ECHAM5 / MPI -OM on the field of study.

These data were simulated under the A1B emission scenario at an atmospheric resolution of 1.9 ° × 1.9 ° and 1.5 ° ocean × 1.5 ° that were used.

3.2. Validation data: CRU (Climatic Research Unit)

These are monthly observed climate data (precipitation, temperature wind speed, relative humidity ...). They are used to verify the parameter values calculated by the model. They were provided by the International Center for Theoretical Physic (ICTP) of half degree square grids aside throughout the world about 1900-2002 periods. These grids were developed by the Climatic Research Unit (CRU) of the of East Anglia University in Norwich [7].

Their main sources are national meteorological agencies, the National Climatic Data Center (NCDC), the World Meteorological Organization (WMO) and other published sources [7, 8].

4. Procedure for the application of the model RegCM3

Climate simulation with RegCM3 includes several steps which essentially is summarized here. These steps range from preparing the parameters count the data generated by the model through the implementation of the model phase.

4.1. Preparation of the model parameters

This is the model parameter preparation phase for use in the simulation and consists of three steps.

o Step 1: Creating Links

This is the modeling step of creating links between the data stored on the various external devices or drives and model, so that it can access various data.

o Step 2: Setting the modeled domain

This step is to define the area to be modeled. The selected area is West Africa, located between longitudes 25 ° E- 25 ° W and latitudes 5 ° S-25 ° N and centered at coordinates (0 °, 15 ° N). On the field, it was applied a horizontal finite difference discretization with square meshes of 60 km² aside. Thus, we get a total of 5005 meshes. So it is from this West African area that the values of climatic parameters were extracted.

o Step 3: Initial conditions and lateral Conditions

This step involves interpolating the mesh of RegCM3 model, data and reanalysis EH5OM EHA1B consist of sea surface temperatures and climate data (temperature, precipitation, wind speed, relative humidity) from the mainland of the area designed to serve as initial conditions in the simulation.

For digital processing the lateral limits of the area, the pattern of the exponential relaxation was used. It is to gradually constrain the variables calculated by the regional model to fit the scale corresponding values in a buffer zone near the lateral boundaries [9].

4.2. Model simulation phase

This is the calculation phase during which the model uses climatic data created in step 3 to start the different simulations. The simulations were performed to monitor the future climate in the medium and long term respectively on the 2031-2040 and 2091-2100 periods compared to the reference period 1991-2000.

o Step 4: Create a working directory

This phase is to create a directory in which the model stores the results of the simulation.

o Step 5: Choice of physical model options

This step is to choose the appropriate physical model options corresponding to the modeled geographic area and the calculation time intervals that give best estimates of simulated parameters.

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4.3. Counting phase of model outputs

This phase of compiling the data came after the simulation phase.

o Step 6: Converting Files

At this stage, it comes to converting binary outcomes in alphanumeric format and to calculate daily and monthly averages of the various climate parameters.

o Step 7: numerical and graphical display

After making conversions, Ferret software is used for numerical analysis and graphics of climate parameters (temperature, humidity, precipitation relative).

5. Estimation methods of model outputs

5.1. Choice of spatial scales operating model results

Three spatial scales were used for the analysis of the performance of the model results. it is the Sahel, the Gulf of Guinea and the Ivory Coast. These different scales for understanding the sub regional and local conditions of climate change. The outputs of the model concerned the rainfall and the monthly and annual average temperatures.

5.2. Evaluation of the reliability of the model

The first interesting question about the reliability of the model is whether this climate can be accurately simulated by RegCM3 model. Indeed, a model is best to simulate the future climate when it is able to correctly reproduce this climate. Validation of the model is presented in the form of comparative analyzes of different results. It shows the degree of adequacy between the observed and calculated values .

Comparisons are first performed with the temperature and precipitation calculated by the model and those observed (CRU) on 1991-2000 period.

Subsequently, the model was tested under real weather conditions with rainfall and temperatures taken a few weather stations of Côte d'Ivoire and Burkina Faso.

5.2.1. Numerical criteria: Residues (Rd) and determination coefficient: R^2

Case of residues (Rd)

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The residue shows whether the climate model overestimates or underestimates the desired parameters. The residue is given by the following formula:

$$Rd = \frac{(X_{cal} - X_{obs}) \times 100}{X_{obs}} \quad (1)$$

If Rd > 0 the model overestimates the calculated parameter
If Rd <0 the model underestimates the calculated parameter
Xcal : Parameter value calculated by the model
Xobs : Parameter value observed

Case of coefficient of determination: R^2 between 0 and 1

The coefficients of determination between values of simulated and observed parameters allow assessing the effectiveness of the model to reproduce climate parameters over the observation period. It is a method widely used for evaluating the performance of climate models both global and regional [3, 10, 11] and is as follows:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(x_{obs} - x_{cal})^2}{\sum_{i=1}^{n}(x_{obs} - \overline{x}_{cal})^2} \quad (2)$$

With:
i: sample size .
When R^2 tends to the value 1, the results are acceptable; below the 0.85 value of R^2, the results are bad.

5.2.1. Graphical methods calculated and simulated monthly average

Using graphical representations such as histograms and scatter plots, rainfall and simulated temperatures are compared with the observed values to test the performance of the model to simulate the climate parameters of West Africa.

6. Results

This section presents the results of climate modeling performed on the West African regions. This is to check the model performance over previously experienced in the period 1991-2000. This allows later whether the raw data of the model can be used for forecasting and planning or whether they must undergo further processing before they use.

6.1. Comparison of simulated monthly temperatures with observed temperatures (CRU) in 1991-2000

The comparison between the monthly temperature over the period 1991-2000 shows that monthly temperatures simulated by the model in the Sahel are slightly higher than the observed temperatures of the CRU (Fig. 2A). This tendency to overestimate monthly temperatures in the Sahel mainly concerns the dry months (February to May and October to December).

In the Gulf of Guinea, there is equality between the values of observed and simulated temperatures (Fig. 2B).

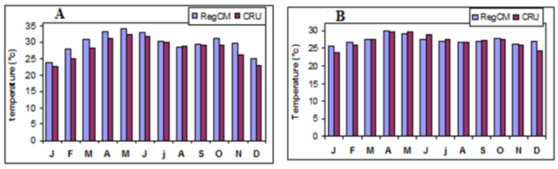

Fig. 2: Monthly Temperatures calculated and observed in the Sahel (A) and the Gulf of Guinea (B) (1991-2000)

Examination of the correlations between the calculated and observed temperatures in the two sub regions namely the Sahel and the Gulf of Guinea (Fig. 3) confirm that the model simulates well the temperatures. Indeed, the calculated correlations give respectively R^2 = 0.88 in the Sahel and R^2 = 0.75 in the Gulf of guinea

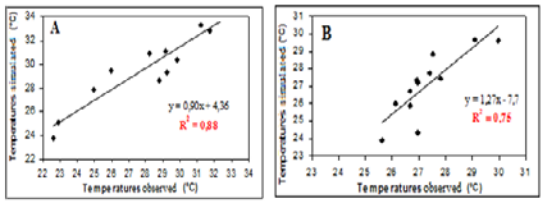

Fig. 3: Linear correlation between calculated and observed monthly temperatures in the Sahel (A) and the Gulf of Guinea (B).

Averaging errors committed by the model in the estimation of monthly temperature values obtained shows that the model overestimates the monthly temperatures in the Sahel at 0.41 % to 13.50 %, except in August when the temperature is 0.54 % underestimated (Table 1). In the Gulf of Guinea, there is a clear difference between the errors of the model during the rainy months and dry months. Indeed, during the wet months (May to October), the model underestimates the temperatures of 1.74% to 3.35 %. During the dry months, the model overestimates the

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temperatures of 1.82 % to 10.26%. Regarding annual temperatures, the average error is 2.53% in the Sahel and 2.17% in the Gulf of Guinea. These uncertainty values on the model with respect to the temperatures are low (average errors less than 15%)

Table 1: Average Error (%) of RegCM3 model when estimating monthly and annual average temperatures in the Sahel and the Gulf of Guinea

Months	Sahel (%)	Gulf of Guinea (%)
January	4,91	8,96
February	11,56	6,34
March	9,66	7,16
April	6,77	1,82
May	6,06	-2,20
June	3,53	-3,35
July	1,86	-1,74
August	-0,54	-1,84
September	0,41	-2,74
October	6,72	-2,36
November	13,50	4,68
December	9,59	10,26
Annual mean error	2,53	2,17

6.2. Comparison of average monthly temperatures simulated by RegCM3 with in situ measured temperatures of Côte d'Ivoire

In order to check the reliability of RegCM3 model, it has been compared average annual temperatures measured twelve synoptic stations (Côte d'Ivoire) with average annual temperatures simulated by the model (Table 2). The averages errors are still relatively low and do not exceed 4%. They vary in all between -1.81 % (Dimbokro) and 3.19% (Yamoussoukro). Specifically, the model underestimates the temperature at a rate of 0.28 °C in Abidjan, 0.04 °C in Bondoukou and 0.5 °C in Dimbokro. In other localities, the model overestimates the temperatures.

Table 2: Mean Errors RegCM3 when the model in estimating temperatures

	Temperature Simulated (°C)	Temperatures observed (°C)	Mean error (%)	Mean error (°C)
Abidjan	26,44	26,73	-1,05	-0,28
San-Pedro	25,75	25,70	0,20	0,05
Gagnoa	26,10	25,76	1,33	0,34
Daloa	26,67	26,62	0,21	0,05
Dimbokro	26,45	26,94	-1,81	-0,50
Yamoussoukro	26,39	25,57	3,19	0,82
Man	25,40	24,67	2,95	0,73
Bouaké	26,29	26,00	1,11	0,29
Bondoukou	26,02	26,03	-0,04	-0,01
Odienné	26,25	25,74	1,97	0,51
Korhogo	27,44	26,88	2,08	0,56
Bèredougou	27,76	27,23	1,97	0,54

6.3. Comparison of simulated quarterly average temperatures RegCM3 with temperatures observed CRU

The comparison of the quarterly average temperatures simulated by RegCM3 model (Fig. 3A) to those observed with the CRU (Fig. 3B) was used to check the reliability of climate model. In general, the model simulates quite well the spatial dynamics of temperatures. However, the model slightly overestimates the temperatures. In fact, temperatures are overestimated in the Sahel regions compared to the Gulf of Guinea. For example, from April to June, the model overestimates the temperatures in the window formed by the northern Senegal and Mali, southern Mauritania and across the Niger. During the period from July to September, the extreme north of the modeled area has high temperatures calculated from those observed. In the Gulf of Guinea, low simulated temperature values are observed to Guinea- Liberia border and central Nigeria which are mountainous areas. From October to December, the calculated temperatures at the coast are significantly lower than the observed values.

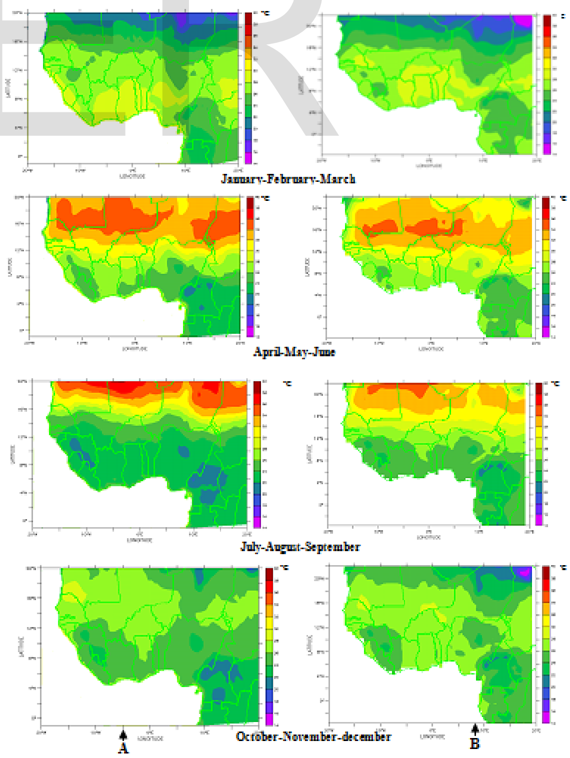

Fig. 3: Map of quarterly temperatures averages calculated (A) and observed (B) in West Africa (1991-2000) with the RegCM3 model.

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6.4. Comparison of Monthly Average rainfall simulated by RegCM3 with precipitation observed CRU

As the temperatures, average monthly rainfall calculated and observed in the Sahel and the Gulf of Guinea during the 1991-2000 period were compared (Fig. 4). It appears that the simulated rainfalls by the model are higher than those from observations in the Sudano-Sahelian region. In the Gulf of Guinea, precipitations calculated by the model are substantially equal to observations.

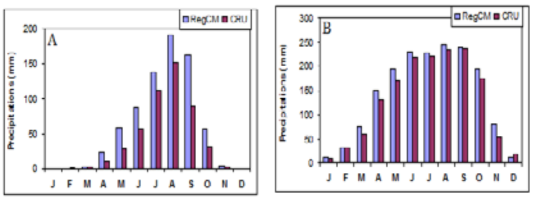

Fig. 4: Monthly precipitation calculated and observed in the Sahel (A) and the Gulf of Guinea (B)

Similarly, linear correlations were found between observed and calculated rainfall in the Sahel and the Gulf of Guinea (Fig. 5). It appears that the calculated monthly precipitation correlate well with the observations of the CRU. Indeed, the determination coefficients (R^2) are respectively in the range of 0.95 and 0.99 in the Sahel and the Gulf of Guinea. These results show that there is very good correlation between the simulated and observed precipitation

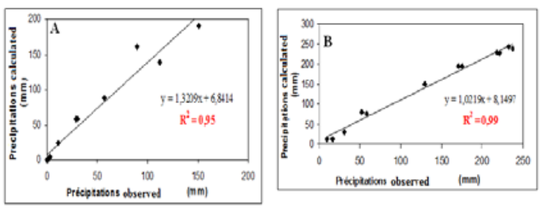

Fig. 5: Linear correlation between the calculated and observed monthly rainfall in the Sahel (A) and the Gulf of Guinea (B)

6.5. Comparison of average annual rainfall simulated by RegCM3 with measured rainfall in situ

The simulated rainfalls were also tested with precipitation measured in situ by the services of the National Meteorological Ivory Coast and Burkina Faso. In order to assess the performance of climate RegCM3 model, errors average related to climate model for estimating rainfall were calculated relative to the in situ values. The results obtained (Table 3) indicate that the average error range from about 1% to 35 % depending on the zones. Areas where uncertainty is 30% are regions of Gagnoa, Abengourou and Bondoukou. However, the annual average error of the localities in question is equal to 23.5%.

Table 3: Annual average Errors climate model (RegCM3) precipitation calculated in relation to in situ precipitation

Meteorologic stations	Precipitation modeled (mm)	Precipitation observed (mm)	Mean error
Abidjan	2149,6	1803,8	**19,17**
Gagnoa	1684,9	1271,5	**32,52**
Daloa	1388,2	1069,8	**29,76**
Man	1725,3	1708,7	**0,969**
Abengourou	1659	1226,3	**35,28**
Bondoukou	1507,5	1117,7	**34,87**
Odienné	1591,8	1383,5	**15,06**
Korhogo	1525	1236,3	**23,41**
Bérégadougou	1327	1104,1	**20,23**
Moyenne annuelle	**1617,6**	**1324,6**	**23,5**

6.6. Mapping of the observed and simulated rainfall in West Africa

The maps (Fig. 6 and 7) show the spatial distribution of monthly precipitation simulated by the model RegCM3 and precipitation observed a few rainy months in West Africa in 1991-2000. The results show that the model overestimates more rainfall compared to those observed. Indeed, the simulated rainfall with the same values as the latitudinal observations occupy positions higher than those derived from observations. Beyond latitude 18 ° N, observations give no rain while the model simulates more than 3 mm of rainfall in June and July. Serious anomalies are also observed in the center of Cameroon. The model underestimates the monthly precipitation on the coast of Liberia. However, the model simulates well the spatial dynamics of monthly precipitation gradient along the continental South-North.

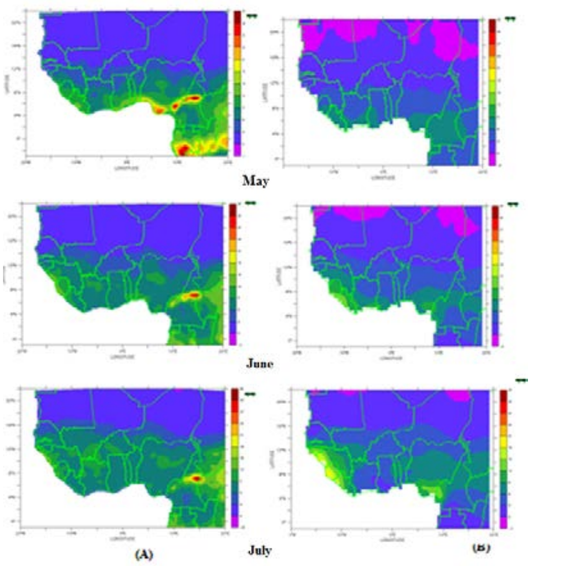

Fig. 6: Map of the monthly average precipitation simulated by RegCM3 model (A) and observed the CRU (B) of the months of May, June and July

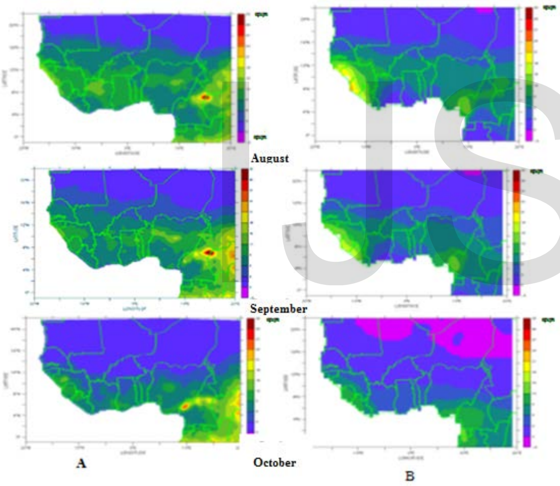

Fig. 7: Map of the monthly average precipitation simulated by RegCM3 model (A) and observed the CRU (B) of the months of August, September and October

6.8. Discussion on performance, weaknesses and uncertainties of the model

The different validation tests on the modeled area have highlighted the weaknesses and performance RegCM3 model. The weaknesses of the model are both qualitative and quantitative.
The qualitative aspect involves the inability of the model to accurately reflect seasonal variations in temperature and precipitation of the Guinean area where the sub-equatorial climate has four seasons including two wet and two dry [3,11]. As regards the quantitative aspect, the model overestimates in most cases the climatic parameters of West Africa to varying degrees. On all spatial scales considered (Sahel, Gulf of Guinea, Ivory Coast), temperatures are better simulated by the model. Indeed, the annual averages calculated through these regions are very low (less than 0.6 ° C). The Sahel and Guinean regions, the model overestimates annual average temperatures of 2.53 % and 2.2 % respectively. At the monthly level, the maximum errors are committed by 13.5 % in November, in the Sahel, and 10.3% in December in the Gulf of Guinea.
In the Gulf of Guinea, the model underestimates the temperatures during rainy.
These low uncertainties are explained by the fact that no high mountains, temperatures are relatively homogeneous spatial variability [11]. This performance results in significant correlations between the calculated and observed temperatures in the Sahel (R^2 = 0.88) and in the regions of the Gulf of Guinea (R^2 = 0.75). Unlike temperature, precipitations are simulated by the model with relatively large mean errors. Indeed, the comparison of observed precipitation (CRU) and those simulated by the model gives average errors ranging from 8.5% in Guinean zone and 48.9% in the Sahel. Ivory Coast and in the watershed Comoe, the average error is 39.73%. However, there is a strong correlation between the average annual rainfall observed and simulated. Such determination coefficient values (R^2) are 0.95 and 0.99 in the Sahel in the Gulf of Guinea. These strong correlations between the calculated and simulated data is used to correct the data calculated by the model in the event that certain values are clearly erroneous. Before any use or exploitation of the results of the model, it is important to correct them. The average errors produced by the model RegCM3 are due to the parameterization of physical phenomena [12, 13] such as convective precipitation, boundary conditions and surface finish. Similarly, RegCM3 climate model using the data derived from EH5OM ECHAM5 global template as initial conditions for the simulation includes errors of this model results. One of the sources of error in this study is the failure to take account of changes in surface condition. Indeed, the dynamics of the interactions between vegetation and atmosphere strongly influences climate through feedback mechanisms [11, 14]. Finally, the observed data (CRU) used to compare those simulated also include measurement errors [15,

16]. Indeed , although the RAW data was provided, in the main, from measured values on the ground , they have been supplemented by interpolated values in areas such as West Africa, where stations measurement are very far apart .

Conclusion

The climate model RegCM3, like other regional climate models such as MM5 (Mesoscale Meteorological Model Release 5) or existing global simulates quite well with meteorological parameters, however, mistakes. Errors those are most important in the estimation of rainfall as temperatures.

Despite this weakness, climate models are the only tool to assess the impact of future climate change. However, it is recommended not to directly use the outputs of the model. Therefore, it is important to express the results in terms of expected changes in future given period relative to a selected reference period. It is in this dynamic for many studies of climate change impacts, temperature and precipitation changes produced by the model are applied to the series observed for perturbed series [17, 18, 19, 20]. These statistical methods are those using chronic abnormalities and the other using variations horizons [3, 21].

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