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Semivariance analysis in the Venezuelan plains under the context of climate change:

a geostatistical view of future projections

Análisis de semivarianza en los llanos venezolanos bajo el contexto del cambio climático: una visión geoestadística de las proyecciones futuras

Análise de semivariância nas planícies venezuelanas no contexto das mudanças climáticas: uma visão geoestatística das projeções futuras

Miguel Ilianovich Silva Borges[1], Rosana del Valle Figueroa-Ruiz[1], Juan Carlos Rey[2] y Nagheley María Mendoza Díaz[1]
[1] Universidad Central de Venezuela, Facultad de Agronomía, Departamento e Instituto de Ingeniería Agrícola
[2] Instituto Nacional de Investigaciones Agrícolas, Centro Nacional de Investigaciones Agropecuarias Maracay, estado Aragua, Venezuela
climamiguel48@gmail.com; valleverde2003@gmail.com; jcrey67@gmail.com; naghely.mendoza@gmail.com

Silva: https://orcid.org/0000-0003-0300-8393
Figueroa-Ruiz: https://orcid.org/0000-0001-9760-5943
Rey: https://orcid.org/0000-0001-7271-3606
Mendoza: https://orcid.org/0000-0003-1973-5114

Abstract Estimating future changes in climate is extremely important for designing climate change adaptation measures. The objective of this research was to map the rainfall of the Venezuelan plains of a reference period and those projected for the 2050s by the GISS-E2-R, MPI-ESM-LR, NCARCCSM 4 and HadGEM2-AO models, under the RCP 4.5 scenario. Ordinary and Universal Kriging was used, analyzing the geostatistical information generated. The results showed the spatial dependence of the rainfall, both for the reference period and in the future. The magnitude of rainfall could increase in a very concentrated way or decrease spatially for the achieved ranges. The dry months would record generalized reductions in rainfall as opposed to the wet months. All models predict concentrated rainfall increases towards the western plains, in the states of Barinas and Apure, as well as to the north of the eastern plains.
KEYWORDS: rains; models; spatial; scenarios; future; kriging.

Resumen Estimar los cambios futuros del clima es sumamente importante para diseñar las medidas de adaptación ante el cambio climático. El objetivo de esta investigación consistió en cartografiar las precipitaciones de los llanos venezolanos de un periodo de referencia y las proyectadas para el período 2050s por los modelos GISS-E2-R, MPI-ESM-LR, NCARCCSM 4 y HadGEM2-AO bajo el escenario RCP 4.5. Se empleó el Kriging Ordinario y Universal, analizando la información geoestadística generada. Los resultados mostraron dependencia espacial de las lluvias tanto para el periodo de referencia como para el futuro. La magnitud de las lluvias pudiera aumentar de forma muy concentrada, o disminuir espacialmente para los alcances conseguidos. Los meses secos registrarían reducciones generalizadas de las lluvias al contrario de los húmedos. Todos los modelos predicen aumentos concentrados de las lluvias hacia los llanos occidentales, en los estados Barinas y Apure, así como al norte de los orientales.
PALABRAS CLAVE: lluvias; modelos; espacial; escenarios; futuro; kriging.

Resumo A estimativa de mudanças futuras no clima é extremamente importante para a elaboração de medidas de adaptação às mudanças climáticas. O objetivo desta pesquisa foi mapear a precipitação das planícies venezuelanas para um período de referência e aquela projetada para a década de 2050 pelos modelos GISS-E2-R, MPI-ESM-LR, NCARCCSM 4 e HadGEM2-AO sob o cenário RCP 4.5. Foi empregada a Krigagem Ordinária e Universal, analisando as informações geoestatísticas geradas. Os resultados mostraram a dependência espacial da precipitação tanto para o período de referência quanto para o futuro. A magnitude das chuvas poderia aumentar de forma altamente concentrada ou diminuir espacialmente para as faixas alcançadas. Os meses secos registrariam reduções generalizadas na precipitação, ao contrário dos meses úmidos. Todos os modelos preveem aumentos concentrados nas chuvas em direção às planícies do oeste, nos estados de Barinas e Apure, bem como ao norte das planícies do leste.
PALAVRAS-CHAVE: precipitação; modelos espaciais; cenários; futuro; krigagem.

1. Introduction

Climate change is possibly the most important global environmental problem today. Due to the nature of the rains, it is difficult to relate them to this phenomenon, especially in particular regions or places, however, some research has attempted to address its effects on rainfall in Venezuela. Based on historical records, a decrease in precipitation amounts has been found in a large part of the country during the months when the rains began and an increase in these amounts at the end of the rainy season (Paredes-Trejo *et al*., 2020) and significant decadal percentage increase in monthly rainfall towards the Caura and Caroní river basins (de Barros Soares *et al*., 2017).

Nowadays, there is more than one tool for the evaluation of the impacts generated by climate change, one of them; being the projection of the climatic variation of climatic variables under the premises of change through models, allowing us to glimpse the possible effects and adaptation alternatives for the future in the face of this problem.

The focus on the study of the effects of climate change in the future in Venezuela has had great emphasis on recent research with results that coincide to a certain extent; Viloria *et al*. (2023) projected for the period 2041–2060, MPI-ESM1.2-LR model and SSP3-7.0 scenario, greater decreases in rainfall in the regions located to the east and center of the country, but with an increase in rainfall from north to south. Romero *et al*. (2023) estimated decreases in aquifer recharge in the Portuguesa state under climate change conditions and the CNRM-CM5 model, while Silva & Mendoza (2021) projected increases in the magnitude and duration of meteorological drought events in agricultural locations in Venezuela for NCAR-CCSM4, GISS-E2-R, NIMR-HADGEM2-AO, MPI-ESM-LR models and RCP 2.6 and RCP 8.5 scenarios.

Accordingly, cartography is ideal for assessing future climate change projections (Kaye *et al*., 2012). The spatial vision of the changes in rainfall and temperatures helps to expose the magnitude of the simulated effects of this phenomenon in a wide geographical space and, therefore, has been one of the most illustrative forms used by the IPCC assessment reports (IPCC, 2014; IPCC, 2022). In this regard, geostatistics has been the most widely used methodology for mapping meteorological variables (Perin *et al*., 2015). This discipline is characterized not only by the spatial estimation of the element but also by providing information on its structure. Kriging, its greatest exponent, is an interpolation methodology based on a space-dependent variance, which interpolates variable values using measured points (Webster & Oliver, 2007). Kriging equation uses an unknown weight of the measured value, which is estimated as the inverse of the semivariance calculated using a spatial continuity model or semivariogram, which, in turn, indicates the autocorrelation structure (Negreiros *et al*., 2010). This semivariogram is modeled and generates a series of parameters that allow geostatistical information to be extracted from the phenomenon, or, in other words, its spatial behavior from a statistical point of view.

In Venezuela, geostatistics has been the technique used to represent rainfall (Rodríguez *et al*., 2013; Cortez *et al*., 2016), as well as in the context of climate change (MINEA, 2017). However, in Venezuela, very few of these investigations have taken advantage of the information derived from geostatistical modeling before interpolation. There is no record of any investigation where rainfall is projected under climate change scenarios and geostatistical information is extracted simultaneously.

The objective of this research was to map the rainfall of the Venezuelan plains corresponding to a reference period and those projected by the atmospheric general circulation models (AGCMs); GISS-E2-R, MPI-ESM-LR, NCARCCSM 4, and HadGEM2-AO, under the RCP 4.5 scenario and the 2050s period. For this, the Ordinary and Universal Kriging was used, which allowed taking advantage of the geostatistical information generated during the process, carrying out an analysis of the semivariance of rainfall, in one of the most important agro-productive regions, projected by the validated AGCMs and which consistently represents the rainfall of the country (ACFIMAN-SACC, 2018). In this way, not only is information on the effects of climate change on rainfall in the region associated with a probability of 75% of all the pathways modeled to date exposed, but it also goes deeper than that illustrated on the maps interpolated through geostatistics.

2. Methodology

2.1 Study area

The research focused on the Venezuelan plains, which are located between 6° and 10° north latitude, and 62° to 72° west longitude (FIGURE 1). The region is made up of the Western, Central, Eastern plains and part of the Deltaic System. Its topography is predominantly flat, ranging from 50 to 200 meters above sea level and they cover 280,000 km^2 (MINEA, 2017). The climate is highly variable, from semi-arid in part of the eastern plains to slightly humid to moderately humid in the Andean foothills and the western plains.

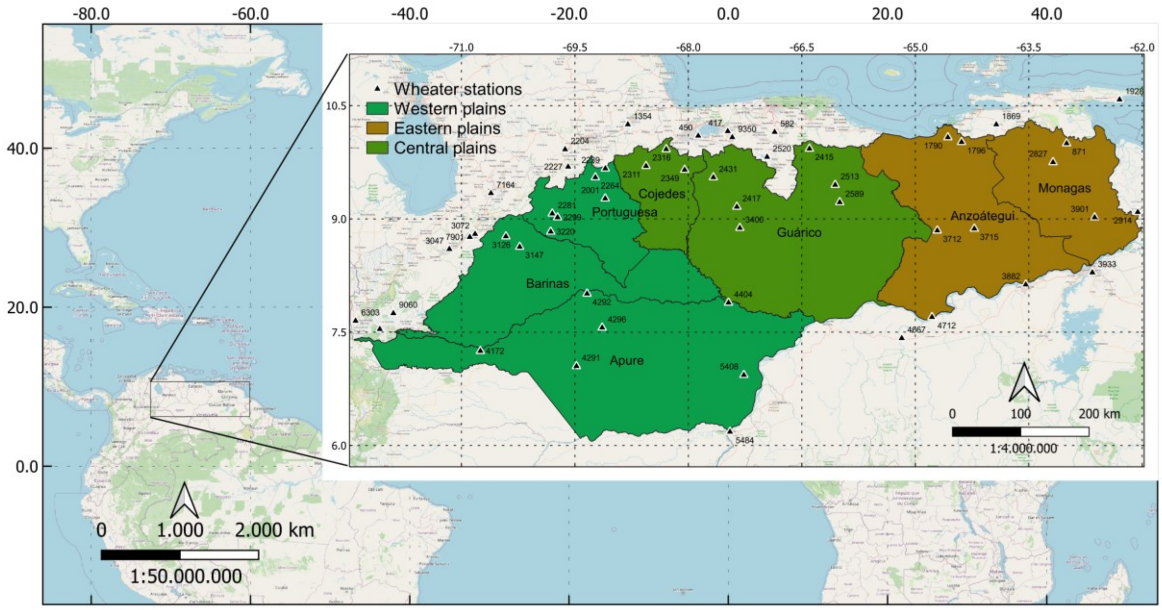

FIGURE 1. Study area and weather stations used in the research

2.2 Climate data

Precipitation data with monthly grouping corresponding to the period 1970-2000 (reference period) from 53 meteorological stations were used. Of the total, 31 stations are within the study area, while the rest of the stations are outside the perimeter of the area to provide information when making the spatial prediction and its representation. These data have the data quality criteria applied in the research of Mendoza & Puche (2007) who previously used those same stations and were provided by the Climate Services Unit for Agriculture and Environment (USICLIMA) of the Faculty of Agronomy of the Central University of Venezuela.

2.3 Exploratory data analysis

Exploratory data analysis is considered the first important step in geostatistical studies, with which unexplored information about the sample is inferred, in this case, the reference period. This was based on the calculation of descriptive measures such as the mean, median, skewness and kurtosis coefficient. Next, the normality of the data was evaluated with the Shapiro-Wilks test, where W tend to be equal to one and it´s p-value must be greater than 0.05 to confirm the normality of the data.

2.4 Generation of future precipitation series.

The future precipitation series were generated from the application of climate change rates to the precipitation series for the reference period. These rates of change correspond to data from the research program on climate change, agriculture, and food security (CCAFS). They are calculated based on the average precipitation data downloaded from the portals http://ccafs-climate.org/data/ and http://www.worldclim.org. The first portal provides climate change data for all general circulation models, while the second corresponds to historical observations of the climate variables that were used as the basis for the CCAFS Program. These rates were calculated using the following steps:

- AGCMs calibrated for Venezuela (ACFIMAN-SACC, 2018): GISS-E2-R, MPI-ESM-LR, NCARCCSM 4 y HadGEM2-AO.
- RCP 4.5 scenario. This corresponds to a trajectory that leaves a forcing of 4.5 Wm-2 for the year 2100 (IPCC, 2014). This scenario is one of the available so far for climate change projections and validated models for Venezuela.
- Future period 2050s.

Procedure for applying exchange rates to the reference period series:

- Download WorldClim v1.4 data from http://www.worldclim.org and http://ccafs-climate.org/data/ in Geo TIFF format (January 10, 2019).
- Extraction of monthly precipitation values from WorldClim v1.4 and future precipitation data. For this step and the previous one, the tools configured in the software for geographic information systems Qgis version 2.14 were used.
- Calculation of deltas relative to the Wolrdclim value, according to equation 1:

$$\Delta = \frac{(\text{CCAFS value} - \text{WorldClim value})}{(\text{WorldClim value})} \qquad (1)$$

- Application of relative deltas of each month, to each of the months of the reference series using equation 2, thus generating eight work series, for each model and scenario:

$$\text{Future rainfall} = (\text{Reference rainfall} + \Delta) * \Delta \qquad (2)$$

2.5 Frequency of occurrence of 75%.

A frequency analysis was performed for each of the series, the reference series and future series. For this, the amounts were ordered from highest to lowest, a ranked was assigned and the rainfall value located at 75% was chosen. This value is interpreted as the rainfall value recorded in 75% of the years.

2.6 Geostatistical methods

Geostatistical techniques were used: Ordinary Kriging (OK) and Universal Kriging (UK). The OK is a form of kriging in which the mean is unknown and is ideal for the prediction of stationary phenomena, while the UK can be considered as a particular case of OK in which the variable follows a trend (Webster & Oliver, 2007), for which information on variables related to the phenomenon to be estimated is used. Due to the fact that the rains of the Venezuelan plains respond to a great extent to the displacement of the Intertropical Convergence Zone during a time of the year, defining the seasonality (Cortez *et al.*, 2016), it was decided to use the OK from November to March and the UK from April to October, using the information of the latitude and longitude of the stations for the latter.

The estimation equation in kriging is the following:

$$\hat{Z}(S_0) = \sum_{i=1}^{N} \lambda_i Z(S_i) \qquad (3)$$

Where; $Z(S_i)$ is the measured value at its location, λ_i is an unknown weight for the measured value, S_0 is the location to predict and N, is the number of measured values. In kriging, the weight λ_i is estimated as the inverse of the semivariance calculated using a spatial continuity model or semivariogram:

$$\bar{y}(h) = \frac{\sum(Z(x+h)-Z(x))^2}{2n} \quad (4)$$

Where $Z(x)$ is the value of the variable at location x , $Z(x+h)$ is another value separated by at a distance h and n is the number of pairs of points separated by that distance (FIGURE 2). A common feature in modeling is the presence of the nugget or random variance (C_0), conceptualized as the discontinuity of the semivariogram at the origin, due to possible measurement errors and/or spatial variability at short distances. Another parameter is the range or scope (a) or distance *h* beyond which the variance does not show spatial correlation, that is, the observations are independent. Finally, the sill, sample variance or threshold (C_0+C_1), defined as the upper limit of the semivariogram, where the model reaches the range. Given that the random variance depends on the measurement scale, it is convenient to calculate the relative random variance (% R.V.) or proportion in relation to the threshold to express the existing degree of dependency (Seidel & Oliveira, 2016).

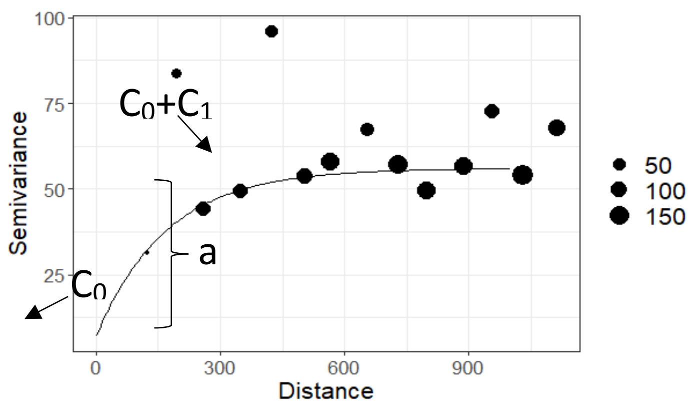

FIGURE 2. Experimental and theoretical semivariogram

2.7 Assessment of rainfall for models and scenario of climate change

The rainfall that would be recorded for the models and the RCP 4.5 scenario compared to the reference period precipitation was evaluated by absolute and relative changes; using map algebra, the absolute precipitation was calculated from the difference between the model precipitation and the reference period precipitation. Relative changes were calculated from the ratio between the above-mentioned difference, subsequently multiplied by 100.

3. Results and discusson

3.1 Exploratory data analysis

The descriptive results of the series are shown in FIGURE 3, where it can be seen that, for each month, the mean and median (a) differ from each other, as well as a positive asymmetry for all months according to the values of the skewness (b). On the other hand, the kurtosis coefficient (b) was less than 3, in 9 of the 12 months analyzed, so it was determined that the values do not present normality. Fact corroborated with the Shapiro-Wilks test for all months that ensure non-normality (c).

Although the absence of normality could be an impediment for the execution of geostatistical methods, if some data transformation is applied, it would allow this limitation to be overcome, as many authors recommend.

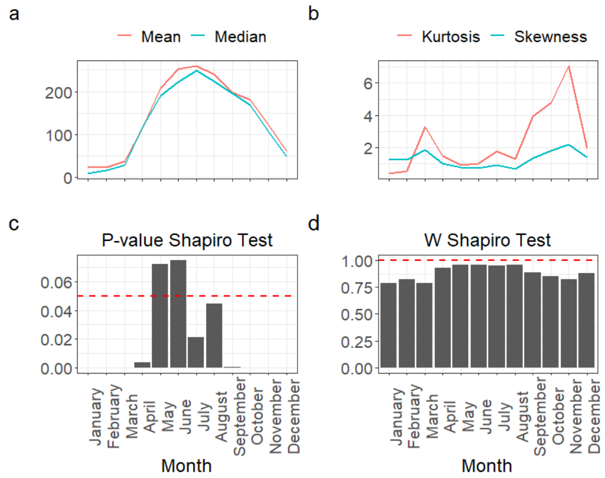

FIGURE 3. Results of exploratory data analysis

However, transformations, for example, the logarithmic on precipitation data, are not always successful since it is common to find zero as a value and it is not defined for the field of logarithms. On the other hand, it has been confirmed that the normality requirement does not improve the result of the application of these methods (Ro & Yoo, 2022), additionally, Kringing is considered the best predictor unbiased linear robust enough to overcome this limitation (Negreiros *et al.*, 2010). Therefore, it was decided to use the original precipitation data.

3.2 Semivariance for the reference period, models and scenarios.

The fitted theoretical semivariograms (FIGURE 4) showed an increase in the semivariance as a function of distance in combination with a transitive and nested effect for all months, indicating the presence of spatial dependence (Webster & Oliver, 2007).

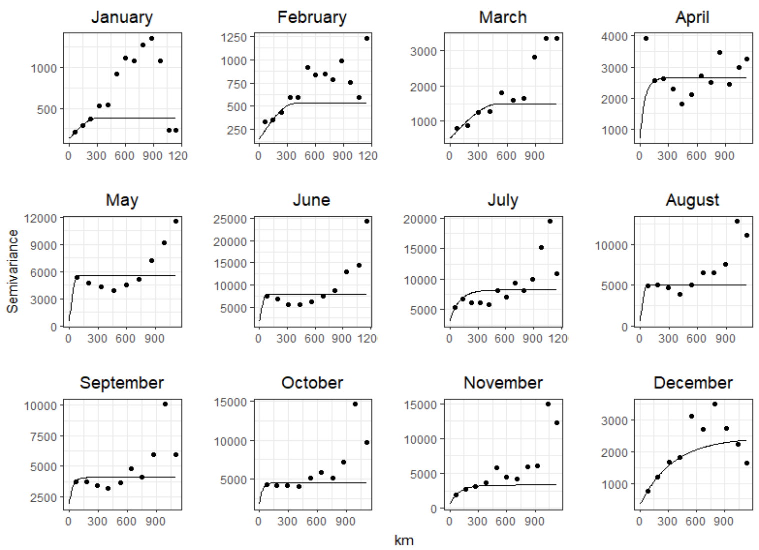

FIGURE 4. Theoretical variograms fitted for each of the months for the reference period

On the other hand, in FIGURE 5 we can see the thresholds for each month, AGCMs, geostatistical model, scenario, and reference period; For most of the AGCMs, a seasonal behavior of the threshold was observed and an increase compared to the reference period, which can be interpreted as an increase in the variability of rainfall in all possible ways, especially in the wet season, such as states Zhang *et al.* (2021) for a future warmer world, attributed to climate change.

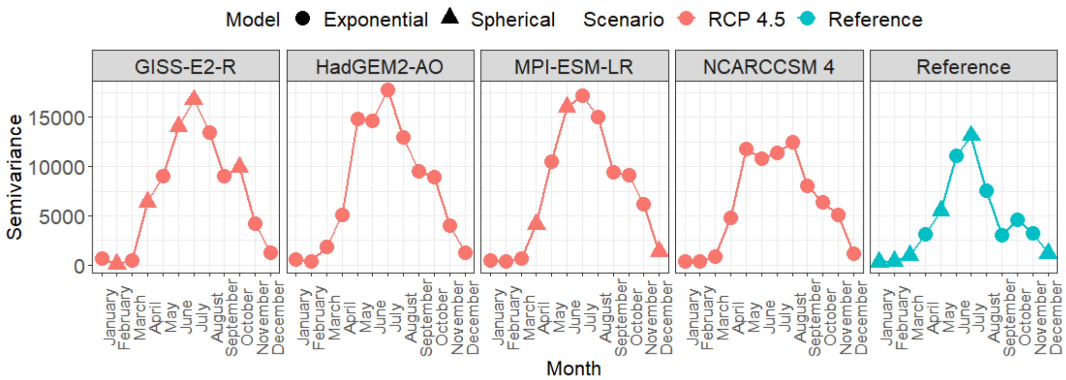

FIGURE 5. Thresholds for each month correspond to the AGCMs, geostatistical model, RCP 4.5 scenario, and reference period

Both the exponential and spherical models prevailed in the reference period and the AGCMs, the exponential being the one that was maintained in the greatest number of months. The use of these models has been common for the geostatistical modeling of rainfall in Venezuela (Rodríguez *et al.*, 2013; Cortez *et al.*, 2016) with interpolated results consistent with rainfall in the region. The results of ranges (a), nuggets (b), and relative variance (c) for the reference period, AGCMs, and scenario are found in FIGURE 6. These variances showed different spatial dependencies between the rainfall values (Cambardella *et al.*, 1994); for the reference period, relative variances between 25 % and 50 % in the variograms revealed a moderate spatial dependence or moderate variation of short-range rainfall for most months except November. The relative variances of less than 25 % from April to July and from October to December, evidenced a high dependence or low variation of rainfall at short distances. The dependency contrasts between the methods expose how the inclusion of longitude and latitude can change the apparent behavior of rainfall in the Venezuelan plains, and in turn, its modeling and kriging, especially for the UK, which has been shown to generate interpolated rainfall surfaces in tropical conditions with spatial trends (de Barros de Sousa *et al.*, 2023).

On the other hand, the predominance of greater ranges was evidenced for the dry season than for the wet season for both methods, not only for the reference period but also for projected rainfall. This may be due to the differences between the amounts registered for both periods in most of the territory, which generates marked variations, characteristic of a seasonal regime (Guo *et al.*, 2022). In the dry season, the amounts of precipitation are very low, so differences of millimeters between one station and another do not produce a significant change in the behavior of rainfall, therefore, the amounts calculated for these months are greater, giving the idea of greater autocorrelation between stations. Otherwise, in the wet season, the amounts of rainfall have a greater variation between the stations, decreasing their autocorrelation and, therefore, expressing a smaller scope in the fit of the models. Moreover, the generation of the rainfall maps for the future scenario and models implied the calculation of a large number of semivariograms and kriging parameters, so it was decided to only include the results of the fitted of the semivariograms and thus facilitate their use in the results and discussion (FIGURE 6).

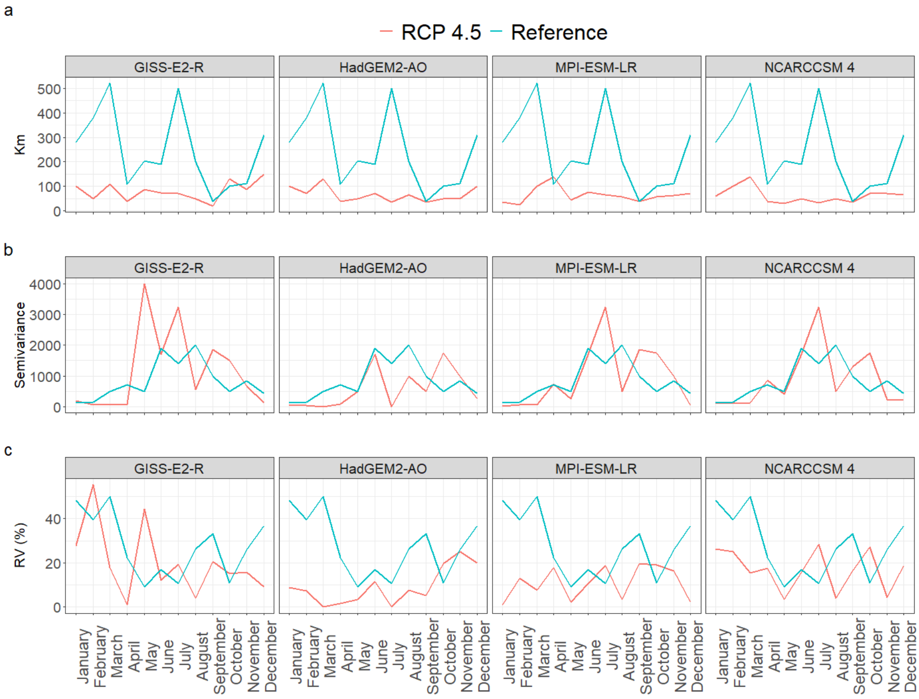

FIGURE 6. Ranges (a), nuggets (b), and relative variances (c) for each month corresponding to the reference period, AGCMs, and RCP 4.5 scenario

The semivariograms maintained the transitive and nested effect seen for the reference period, which shows the presence of spatial dependence on rainfall. The ranges decreased compared to the reference period, mainly for the dry months. The decrease in the percentage of relative variance achieved for the scenario and for all the models analyzed was verified. This relative variance was less than 20 % for most of the months, including in some cases 0 %, which shows that the rainfall could be highly correlated, and indicate that their magnitude could increase spatially in some months, which would imply an increase in the spatial concentration of rainfall under RCP 4.5 scenario and for most of the AGCMs. This situation can also be seen in the decrease in the range for all months and all AGCMs, coinciding with the increase in the concentration of rainfall for the future, as stated by the IPCC (2022) for tropical conditions.

The results of the semivariograms show the influence of climate change according to the scenario used in the investigation; the radiative forcing projected by the RCP 4.5 scenario would have a determined influence on a high surface warming for the future period, which, in turn, associated with a region with a marked convergence of humidity, would generate greater instability and intense rainfall, in an area where rainfall is largely subject to a convective origin (Adler *et al*., 2018). Atmospheric thermodynamic processes exacerbated by climate change are associated with increased precipitation extremes (Lau *et al*., 2023) and have also been considered primary drivers of climate change and climate variability (O'Gorman, 2012). Finally, the decrease in the ranges in the semivariograms could be related to the increase in the spatial concentration of rainfall affected by climate change and whose response is projected by the AGCMs (IPCC, 2014; IPCC, 2022).

3.3 Spatial distribution of rainfall for reference period, models and scenario.

The results of the interpolation of the precipitations corresponding to the reference period, AGCMs, and scenario are shown in FIGURE 7. It can be seen that the precipitation records are lower from December to March in most of the plains compared to the rest of the months. The amounts increase progressively in all the plains for the following months and then decrease. It is observed that the records are higher in the western plains than in the eastern ones. This behavior is consistent with the activity of the intertropical convergence zone, which is responsible for the generation of rainfall in the Venezuelan plains and which defines the seasonality of the region (Misra, 2023). Likewise, the efficiency of the models in emulating such seasonality and behavior is also appreciated, as collected by ACFIMAN-SACC (2018).

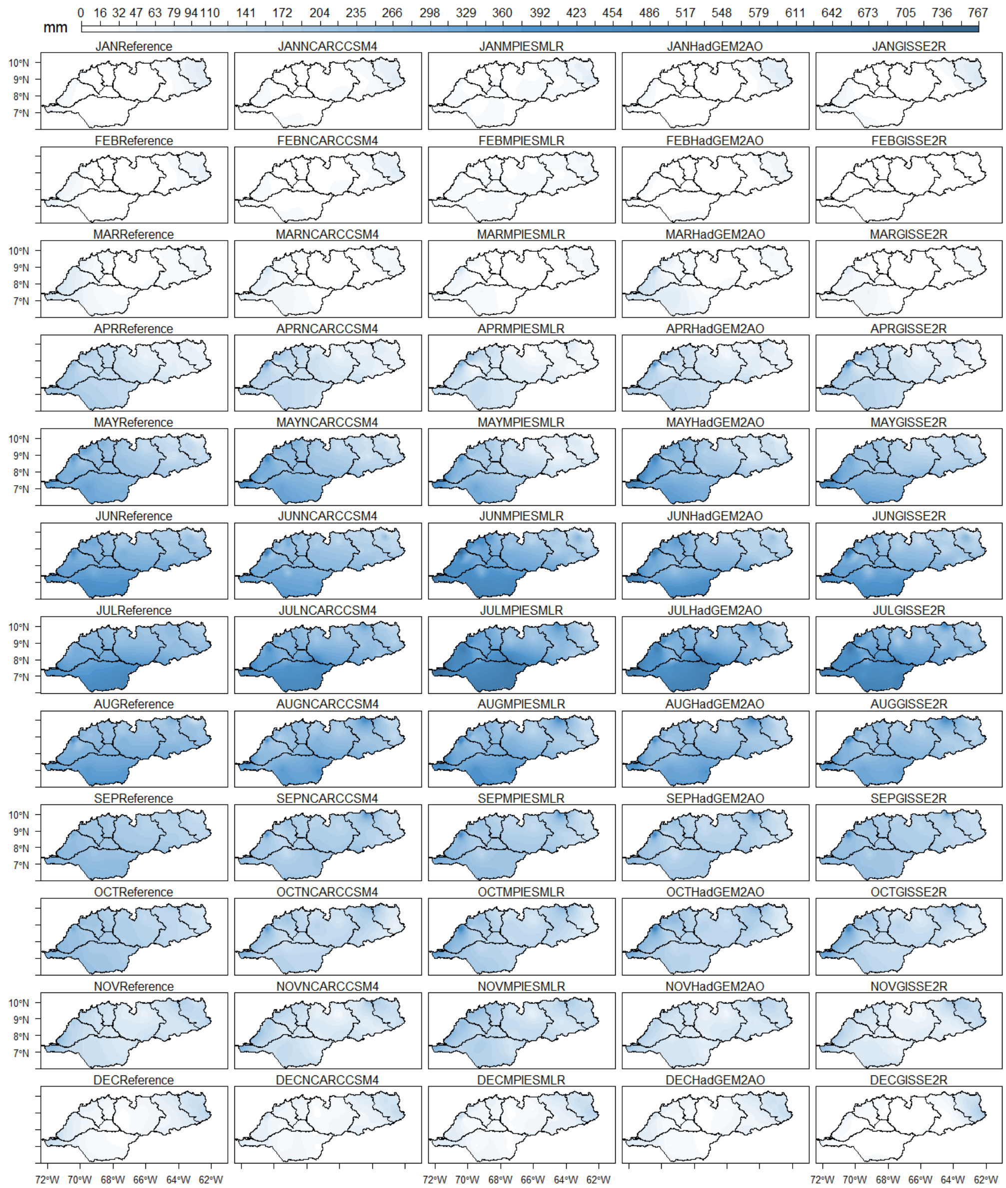

FIGURE 7. Monthly spatial distribution of rainfall in the Venezuelan plains corresponding to the reference period, models and scenarios

Maximum rainfall records for the reference period reached 486 mm, while for some of the AGCMs, up to 767 mm would be recorded, specifically, to the northwest of the plains, further north in the state of Barinas. FIGURE 8 shows the spatial distribution of absolute rainfall changes and FIGURE 9 shows the spatial distribution of relative rainfall changes. Rainfall reductions ranged from 97 % or up to 151 mm absolute decrease to 977 %- or 339-mm increase compared to the reference period.

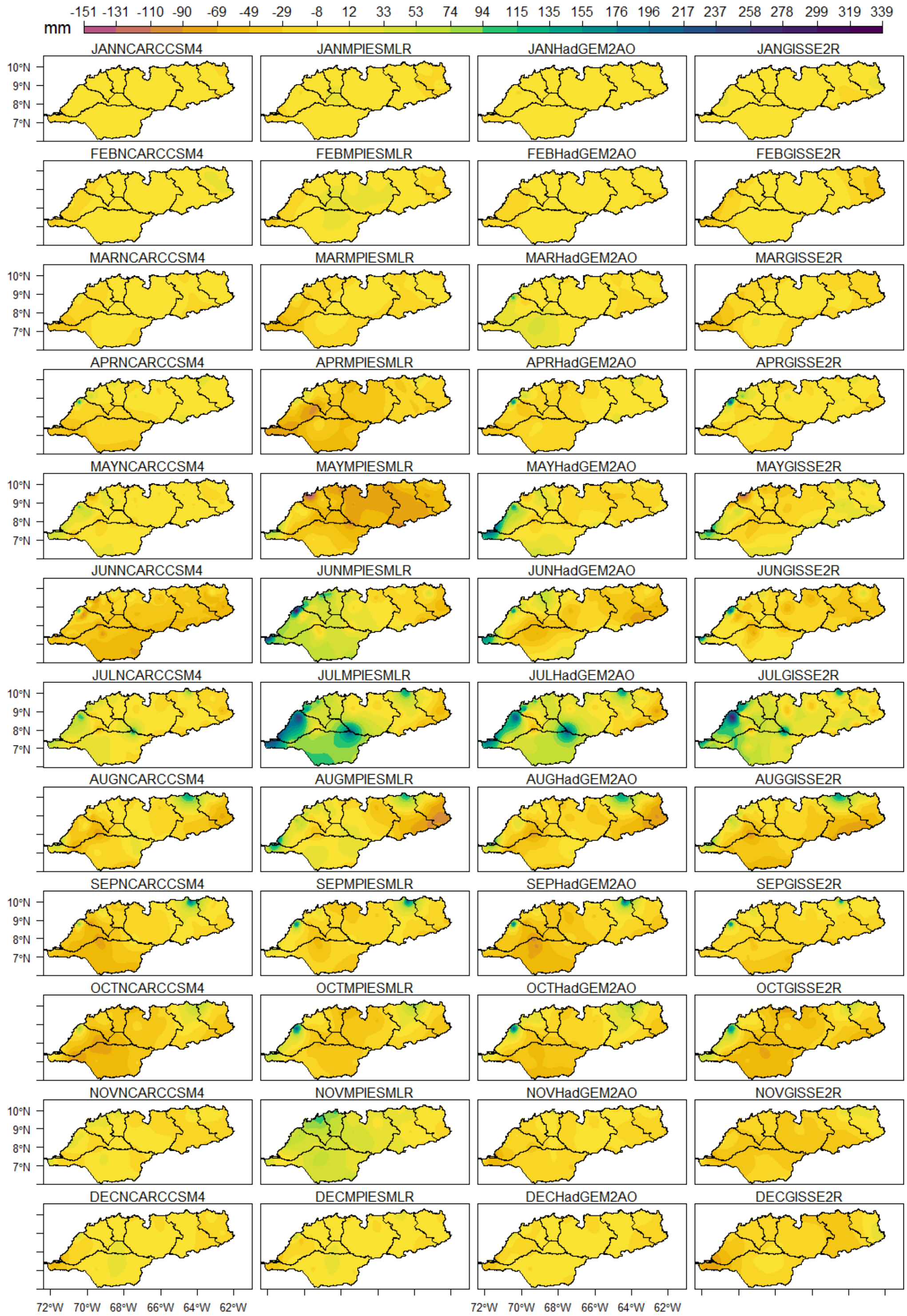

FIGURE 8. Spatial distribution of absolute rainfall changes for the models and RCP 4.5 scenario with respect to the reference period

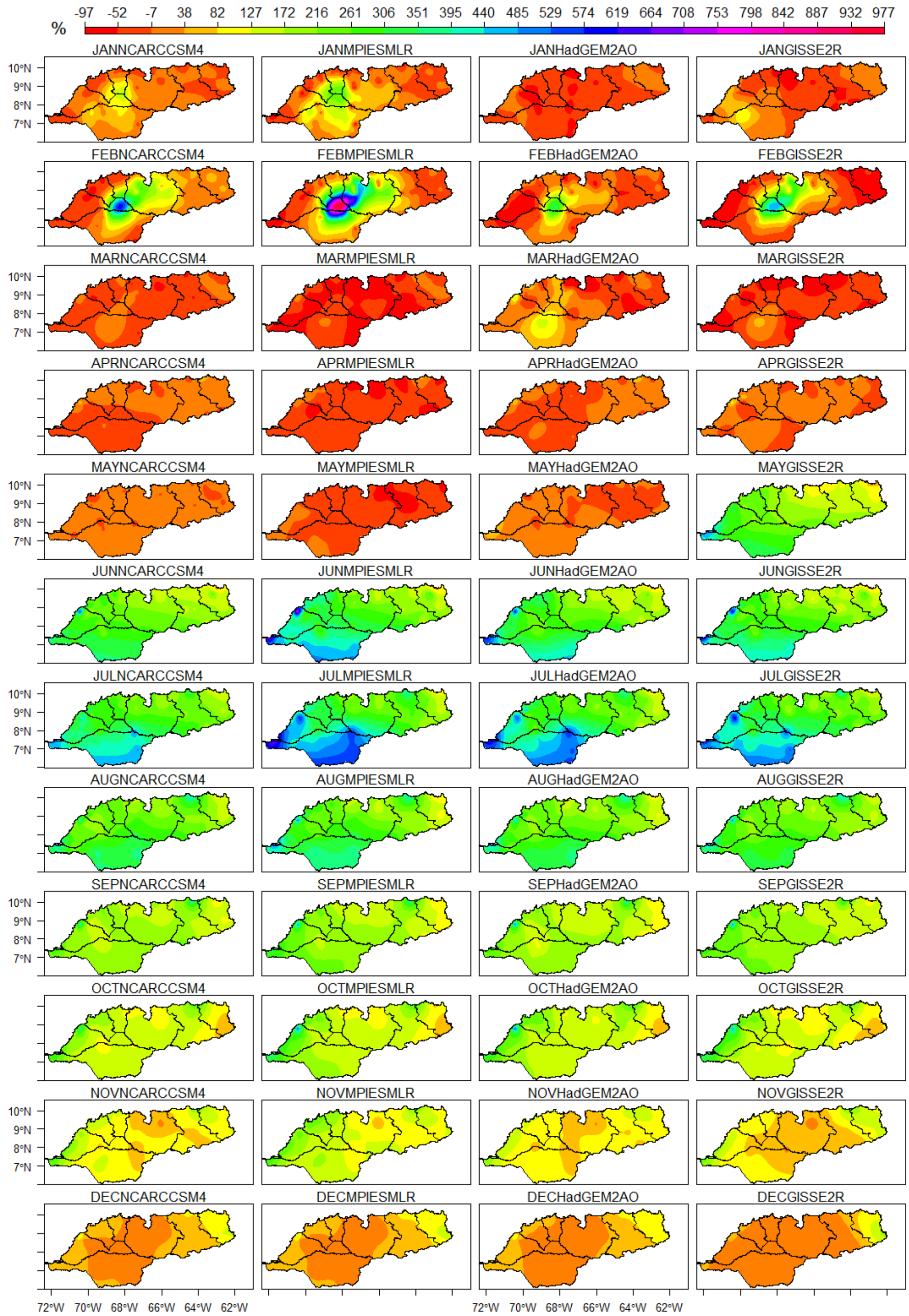

FIGURE 9. Spatial distribution of relative rainfall changes for the models and RCP 4.5 scenario with respect to the reference period

It could be seen that the reductions in rainfall would be located in the dry months, while the increases would be displaced towards the wet months, except for February, where it is possible to appreciate an increase in the form of concentric rings towards the west of Barinas state for all AGCMs, especially the MPI-ESM-LR model, where the maximum value of increase is reached, being this, between 12 to 33 mm absolute. This would mean a significant increase for a month of the year considered traditionally dry, which could generate important impacts on that area. Such a response to the rains during the rainy season has been documented in other investigations, as demonstrated by Qian & Chen (2014) and Wu *et al.* (2016) that climate change generates a change in the pattern of rainfall from tropical regions; of "warmer-gets-wetter" and "wet-gets-wetter", therefore, for the AGCMs and scenario evaluated in this research, this behavior is likely to be recurring in the future.

During the rainy period, the eastern plains recorded lower amounts of rainfall than the central plains, and the central plains recorded less rainfall than the western plains. This same behavior is observed in the rainfall increases, which progressively increase from east to west in all the plains, which is consistent with what has been traditionally recorded for the region (Cortez *et al.*, 2016) and what is projected for the future (Viloria *et al.,* 2023). June, July, and August would register the highest increases, mainly in Apure, Barinas, and Anzoátegui; towards the west and the easternmost point and north of Barinas, east and northwest of Apure, and north of Anzoátegui. The north of Barinas would register the most concentrated increase in rainfall spatially, from June to October in all AGCMs.

The results of both semi-variance and mapping showed a marked spatial concentration of rainfall, both in time and space in some areas of the plains; north of Barinas and other areas of the western plains, which would generate extremely important impacts in an area where rainfall for the reference period is highly concentrated and aggressive (Lobo *et al.*, 2010). This would increase the risk of landslides and erosion in these areas, with potential impacts on their localities and ecosystems, mainly towards the northeast of Barinas. This would imply the disappearance of agricultural practices that could not survive under these conditions or even the mobilization of vulnerable settlements in these areas. On the other hand, the decrease in rainfall projected by the models is consistent with other research where a drier future is projected for the same region (MINEA, 2017; Romero *et al.,* 2023; Viloria *et al.*, 2023) and follows the rainfall trend evaluated so far (Paredes-Trejo *et al.*, 2020).

Changes in rainfall in the Venezuelan plains could have important implications on their natural and agricultural systems; decreases in rainfall could negatively influence rainfed agricultural cycles and compromise Venezuela's food security through crop losses due to high rainfall variability (ECLAC, 2020) where small and medium farmers could suffer the worst effects thanks to their dependence on rainfed agriculture (Imbach *et al.,* 2017), especially in drought conditions that could intensify in magnitude and duration for the same region (Silva & Mendoza, 2021), increasing the need to apply efficient irrigation, in a future context, where there could also be potential impacts on the flows of different basins (Sebastiani *et al.,* 2007; Romero *et al.,* 2023).

4. Conclusions

Geostatistical methodologies made it possible to provide highly relevant information on the natural behavior of rainfall in the Venezuelan plains region. The description of the simulated rainfall according to its magnitude compared to the reference period was coincident between the AGCMs to some extent. Important increases in rainfall would be spatially concentrated in contrast to generalized reductions. However, it was verified that the differences between the AGCMs were related more to the magnitude of the amounts of precipitation than to spatial alterations. Therefore, the strategies that are applied to this must previously evaluate each AGCM in a particular way to know the extreme values of rainfall provided by each one and thus be able to develop comprehensive strategies that cover all possible detrimental effects. The scenario showed for all AGCMs a drier future for most of the Venezuelan plains with significant and very concentrated increases, whose effects would be significant in a transcendental geographic area for Venezuela, so that, if adaptation mechanisms are not applied in the face of this threat, food security, current agricultural management, and biodiversity would be compromised for the future.

5. Reference quoted

ADLER, R. F.; SAPIANO, M. R. P.; HUFFMAN, G. J.; WANG, J. J.; GU, G.; BOLVIN, D.;...& D. SHIN. 2018. "The Global Precipitation Climatology Project (GPCP) Monthly Analysis (New Version 2.3) and a Review of 2017 Global Precipitation". *Atmosphere*, 9(4): 138.

ACADEMIA DE CIENCIAS FÍSICAS, MATEMÁTICAS y NATURALES / SECRETARIA ACADEMICA de CAMBIO CLIMATICO (ACFIMAN-SACC). 2018. *Primer reporte academico de cambio climatico.* Resumen para responsables de Políticas en Cambio Climático para Venezuela: Contribución de los Grupos de Trabajo I, II y III al Primer Reporte Académico de Cambio Climático (PRACC) de SACC, de la (ACFIMAN) de Venezuela. [A. VILLAMIZAR; E. BUROZ CASTILLO; R. LAIRET CENTENO & J. A. GÓMEZ (Eds.)]. Ediciones Acfiman – Citeci. Caracas, Venezuela.

CAMBARDELLA, C. A.; MOORMAN, T. B.; PARKIN, T. B.; KARLEN, D. L.; TURCO, R. F. & A. E. KONOPKA. 1994. "Field-scale variability of soil properties in Central Iowa soils". *Soil Science Society of America Journal*, (58): 1.501-1.511.

CORTEZ, A.; RODRÍGUEZ, M.; REY J. C.; OVALLES, F.; GONZALEZ, W.; PARRA, R.;...J. MARQUINA. 2016. "Variabilidad espacio-temporal de la precipitación en el Estado Guárico, Venezuela". *Rev. Fac. Agron. (LUZ),* 33(3): 292-310.

DE BARROS SOARES, D.; LEE, H.; LOIKITH, P. C.; BARKHORDARIAN, A. & C. R. MECHOSO. 2017. "Can significant trends be detected in surface air temperature and precipitation over South America in recent decades?" *International Journal of Climatology,* 37(3): 1.483-1.493.

DE BARROS DE SOUSA, L.; DE ASSUNÇÃO MONTENEGRO, A. A.; DA SILVA, M. V.; ALMEIDA, T. A. B.; DE CARVALHO, A. A.; DA SILVA, T. G. F.:... & J. L. M. P. DE LIMA. 2023. "Spatiotemporal analysis of rainfall and droughts in a semiarid basin of Brazil: Land use and land cover dynamics". *Remote Sensing,* 15(10): 2.550.

ECLAC. 2020. *The 2030 Agenda for Sustainable Development in the New Global and Regional Context: Scenarios and Projections in the Current Crisis*. ECLAC. Santiago, Chile.

GUO, J.; HU S. & Y. GUAN. 2022. "Regime shifts of the wet and dry seasons in the tropics under global warming". *Environmental Research Letters,* (17):10.

IMBACH, P.; BEARDSLEY, M.; BOURONCLE, C.; MEDELLIN, C.; LÄDERACH, P.; HIDALGO, H.;...& C. DONATTI. 2017. "Climate change, ecosystems and smallholder agriculture in Central America: an introduction to the special issue". *Climate Change*, 141(1): 1-12.

IPCC. 2022 *Climate Change 2022: Impacts, Adaptation, and Vulnerability*. *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [H.-O. PÖRTNER; D. C. ROBERTS; M. TIGNOR; E. S. POLOCZANSKA; K. MINTENBECK; A. ALEGRÍA; M. CRAIG; S. LANGSDORF; S. LÖSCHKE; V. MÖLLER; A. OKEM;

B. RAMA (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York. NY, USA.

IPCC. 2014. 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.

KAYE, N. R.; HARTLEY, A. & D. HEMMING. 2012. "Mapping the climate: guidance on appropriate techniques to map climate variables and their uncertainty". *Geoscientific Model Development*, (5)1: 245-256.

LAU, W. K. M.; KIM, K. M.; HARROP, B. & L. R. LEUNG. 2023. "Changing characteristics of tropical extreme precipitation–cloud regimes in warmer climates". *Atmosphere*, 14(6): 995.

LOBO, D.; CORTEZ, A.; RODRÍGUEZ, M.; OVALLES, F.; REY, J. C.; GABRIELS, D.;...y R. PARRA. 2010. "Análisis de la agresividad y concentración de las precipitaciones en Venezuela. I. Región de los llanos". *Bioagro*, 22(3): 169-176.

MENDOZA, N. y M. PUCHE. 2007. "Evaluación de la ocurrencia de sequía en localidades de Venezuela". *Rev. Fac. Agron. (LUZ)*, 24 (4): 661-678.

MINISTERIO DEL PODER POPULAR PARA ECOSOCIALISMO y AGUAS (MINEA). 2017. *Segunda Comunicación Nacional ante la Convención Marco de las Naciones Unidas sobre Cambio Climático*. Fundambiente. Caracas, Venezuela.

MISRA V. 2023. "Intertropical Convergence Zone". In: *An Introduction to Large-Scale Tropical Meteorology*. Springer Atmospheric Sciences. Springer, Cham. UK.

NEGREIROS, J.; PAINHO, M.; AGUILAR, F. & M. AGUILAR. 2010. "Geographical Information Systems Principles of Ordinary Kriging Interpolator". *Journal of Applied Sciences*, (10): 852-867.

O'GORMAN, P.A. 2012. "Sensitivity of tropical precipitation extremes to climate change". *Nature Geoscience*, (5): 97-700.

PAREDES-TREJO, F.; BARBOSA-ALVES, H.; MORENO-PIZANI, M. A.; FARÍAS-RAMÍREZ, A. y D. RODRÍGUEZ. 2020. "Cambio climático: ¿altera el régimen de precipitaciones y caudales en Venezuela? Ríos en Riesgo de Venezuela", 7, 137-147. En: D. RODRÍGUEZ-OLARTE (Editor), *Ríos en riesgo de Venezuela*. Volumen 3. Colección Recursos hidrobiológicos de Venezuela. Universidad Centroccidental Lisandro Alvarado (UCLA). Barquisimeto, Lara, Venezuela.

PERIN, E.; VIANNA, L.; RICCE, W.; MASSIGNAM, A. & C. PANDOLFO. 2015. "Interpolação das variáveis climáticas temperatura do ar e precipitação: revisão dos métodos mais eficientes". *Gegografia*, 40(2): 269-289.

QIAN, C. & G. CHEN. 2014. "Warmer-get-wetter or wet-get-wetter? A criterion to classify oceanic precipitation". *Journal of Ocean University of China*, (13): 552–560.

RODRÍGUEZ, M.; CORTEZ, A.; OLIVARES, B.; REY, J. C.; PARRA, R. y D. LOBO. 2013. "Análisis espacio temporal de la precipitación del estado Anzoátegui y sus alrededores". *Agronomía Tropical*, 63(1-2): 57-65.

ROMERO, M.; GUTIÉRREZ-CH, J. & H. JÉGAT. 2023. "Efecto del cambio climático sobre la recarga natural de un acuífero: Un caso de estudio en el estado Portuguesa-Venezuela". *Revista Ciencia e Ingeniería*, (44)2: 101-112.

RO, Y. & C. YOO. 2022. "Numerical Experiments Applying Simple Kriging to Intermittent and Log-Normal". *Water*, 14(9): 1-17.

SEBASTIANI, M.; MORENO, M.; SOTO, A.; AGUIRRE, E.; CAMACHO, L.; MEDINA, R.;... y A. ZAMORA. 2007. "Propuesta para la evaluación ambiental estratégica de zonas especiales de desarrollo sustentable (ZEDES cuenca del río Unare, estados Anzoátegui y Guárico-Venezuela". *Revista Geográfica Venezolana*, 48(1): 33-58.

SEIDEL, E.J & M. S. OLIVEIRA. 2016. "A classification for a Geostatistical Index of Spatial Dependence". *Revista Brasileira de Ciência do Solo*, (40): 1-10.

SILVA, M. y N. MENDOZA. 2021. "Evaluación de la sequía meteorológica en locaciones agrícolas de Venezuela bajo proyecciones futuras de cambio climático". *Rev. Fac. Agron. (LUZ),* 38(3): 548-572.

VILORIA, J. A.; OLIVARES, B. O.; GARCIA, P.; PAREDES-TREJO, F. & A. ROSALES. 2023. "Mapping projected variations of temperature and precipitation due to climate change in Venezuela". *Hydrology*, 10(4): 96.

WEBSTER, R. & M. OLIVER. 2007. *Geostatistics for Environmental Scientists*. Second Edition Wiley. Chichester. UK.

WU, H. T. J. & W. K. M. LAU. 2016. "Detecting climate signals in precipitation extremes from TRMM (1998–2013) Increasing contrast between wet and dry extremes during the global warming hiatus". *Geophysical Research Letters*, 43(3): 1.340-1.348.

ZHANG, W.; FURTADO, K.; WU, P.; ZHOU, T.; CHADWICK, R.; MARZIN, C.;... & D. SEXTON. 2021. "Increasing precipitation variability on daily-to-multiyear time scales in a warmer world". *Science Advances*, (7)31: 1-11.

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