STATISTICAL DOWNSCALING OF SUMMER PRECIPITATION IN COLOMBIA

Reiner PALOMINO-LEMUS[1,2], Samir CÓRDOBA-MACHADO[1,2],
Sonia Raquel GÁMIZ-FORTIS[1], Yolanda CASTRO-DÍEZ[1],
María Jesús ESTEBAN-PARRA[1]
[1] Department of Applied Physics, University of Granada, Granada, Spain
[2] Technological University of Chocó, Colombia
rpalomino@ugr.es, scordobam1@ugr.es, srgamiz@ugr.es, ycastro@ugr.es, esteban@ugr.es

ABSTRACT

In this study an statistical downscaling (SD) model using principal component regression (PCR) for simulating summer precipitation in Colombia during the period 1950-2005, has been build, and the climate projections during the 2071-2100 period by applying the obtained SD model have been obtained. For these ends the PCs of the SLP reanalysis data from NCEP were used as predictor variables and the observed gridded summer precipitation as predictand variables. The period 1950-1993 was utilized for calibration and 1994-2010 for validation. The Bootstrap with replacement was applied to provide estimations of the statistical errors. All models perform reasonably well at the regional scales, and the spatial distribution of the correlation coefficients between predicted and observed gridded precipitation values show high values (between 0.5 and 0.93) along Andes range, north and north Pacific of Colombia.

The ability of the MIROC5 GCM to simulate the summer precipitation in Colombia, for present climate (1971-2005), has been analyzed by calculating the differences between the simulated and observed precipitation values. The simulation obtained by the GCM strongly overestimates the precipitation along a horizontal sector through the center of Colombia, especially important at the east and west of the country. However, the SD model applied to the SLP of the GCM shows its ability to faithfully reproduce the rainfall field. Finally, in order to get summer precipitation projections in Colombia for the period 1971-2100, the downscaling model, recalibrated for the total period 1950-2010, has been applied to the SLP output from MIROC5 model under the RCP2.6, RCP4.5 and RCP8.5 scenarios. The changes estimated by the SD models are not significant under the RCP2.6 scenario, while for the RCP4.5 and RCP8.5 scenarios a significant increase of precipitation appears regard to the present values in all the regions, reaching around the 27% in the NC region under the RCP8.5 scenario.

Keywords: Statistical downscaling, Precipitation, Principal component regression, Climate change, Colombia.

RESUMEN

En este trabajo se ha construido un modelo de downscaling estadístico (DS) usando el método de regresión de componentes principales (PCR) para simular la precipitación de verano en Colombia durante el periodo 1950-2005, y se han obtenido sus proyecciones durante el periodo 2071-2100 aplicando el modelo obtenido. Para ello, se han usado las PCs de los datos de SLP de reanálisis del NCEP como variables predictoras y las series de precipitación observada en cada punto de rejilla como predictando. El periodo 1950-1993 ha sido utilizado para calibración y el 1994-2010 para validación. Para proporcionar estimaciones del error estadístico, se ha aplicado el método de Bootstrap con reemplazo. Todos los modelos representan razonablemente bien la precipitación a escala regional, y la distribución espacial de los coeficientes de correlación entre las series de valores predichos y observados en rejilla, muestra altos valores (entre 0.5 y 0.93) a lo largo de la cadena de los Andes, norte y Pacífico norte de Colombia.

Se ha analizado la habilidad del GCM MIROC5 para simular la precipitación de verano en Colombia para clima presente (1971-2005), calculando las diferencias entre los valores de precipitación simulados y observados. La simulación obtenida por este GCM sobrestima fuertemente la precipitación a lo largo de una franja horizontal que atraviesa el centro de Colombia y resulta especialmente importante al este y al oeste del país. Sin embargo, el modelo de SD muestra su habilidad para reproducir fielmente el campo de precipitación. Finalmente, para obtener proyecciones de la precipitación de verano en Colombia para el periodo 1971-2100, el modelo de SD, recalibrado para el periodo total 1950-2010, se ha aplicado a las salidas de SLP del modelo MIROC5 bajo los escenarios RCP2.6, RCP4.5 y RCP8.5. Los cambios estimados por los modelos de SD bajo el escenario RCP2.6 no resultan significativos en ninguna región, mientras que para los escenarios RCP4.5 y RCP8.5 se muestra un incremento significativo respecto a los valores observados en clima presente en todas las regiones que alcanza el 27% en la región norte-centro bajo el escenario RCP8.5.

Palabras clave: Downscaling estadístico, Precipitación, Regresión de componentes principales, Cambio climático, Colombia.

1. INTRODUCTION

Global Climate Models (GCMs) are the most appropriate tools for modeling future global climate change. Changes in precipitation at local and regional scales remain a challenge for the current GCMs. Despite a significant advance in computing capacities, the spatial resolution of GCMs usually is not able to reliably provide future changes in the simulated precipitation (IPCC, 2007; Wilby et al., 2004).

At regional scale, the interaction between the topography and the atmospheric circulation has a strong influence on the climate variability. Colombia is located in a topographically complex area in the northwestern South America, where the meridional migration of the ITCZ along with the Andes mountain range has a significant influence on the Colombian rainfall. The main characteristics of the atmospheric circulation associated with intense precipitation events in this region, directly and indirectly affect economy, ecosystems and society (Alexander et al., 2002; Barsugli and Sardeshmukh, 2002).

Many recent published studies about precipitation forecasting at local scale, have focused on application of statistical downscaling (SD) (Wilby et al., 2004; Christensen et al., 2007; Maraun et al., 2010). The idea of SD is to generate estimates of regional or local climate variables derived from larger-scale predictor variables. Some of the most commonly used methods include Principal Component Regression (PCR) and Partial Least Squares Regression (PLS). Several studies have suggested SD as an instrument in seasonal rainfall forecasts particularly for Colombia (Eden et al., 2014).

The main aims of this study are to build an SD model using PCR for simulating seasonal precipitation in Colombia during the period 1950-2005, and to obtain climate projections of seasonal precipitation in Colombia during the period 2071-2100 by applying the SD model.

2. DATA

The database used in this study include the monthly precipitation data for Colombia in the period 1950–2010, provided by the Global Precipitation and Climatology Center (GPCC, version 6.0). This database consists of a 0.5°×0.5° grid.

As predictor variable, the mean monthly sea level pressure (SLP) available from the National Centers for Environmental Prediction-National Center for Atmospheric Research (NCEP-NCAR reanalysis project), which has a horizontal grid scaling of 2.5°×2.5° (Kalnay et al., 1996), has been used.

The datasets comprise the gridded June-July-August (JJA) total values for each year covering the area 5.25ºS–12.75ºN, 80.25ºW–6.25ºW, for precipitation, and the average summer values in the area 30ºS–30ºN, 180ºW–30ºW) for SLP (Figure 1).

In addition, four target regions for the precipitation in Colombia were selected:
- (1) Northwestern Colombia region (NWC) [8.25°N–4.25°N, 78.25°W–76.25°W].
- (2) Southwestern Colombia region (SWC) [4.25°N–1.25°S, 78.25°W–76.25°W].
- (3) Northern Colombia region (NC) [14.75°–8.25°N, 77.75°W–71.25°W].
- (4) Northcenter Colombia region (NCC) [8.25°–4.25°N, 75.75°–71.75°W].

For each region, the average total rainfall of summer (JJA) along the 61-yr period, from 1950 to 2010, were generated from GPCC data.

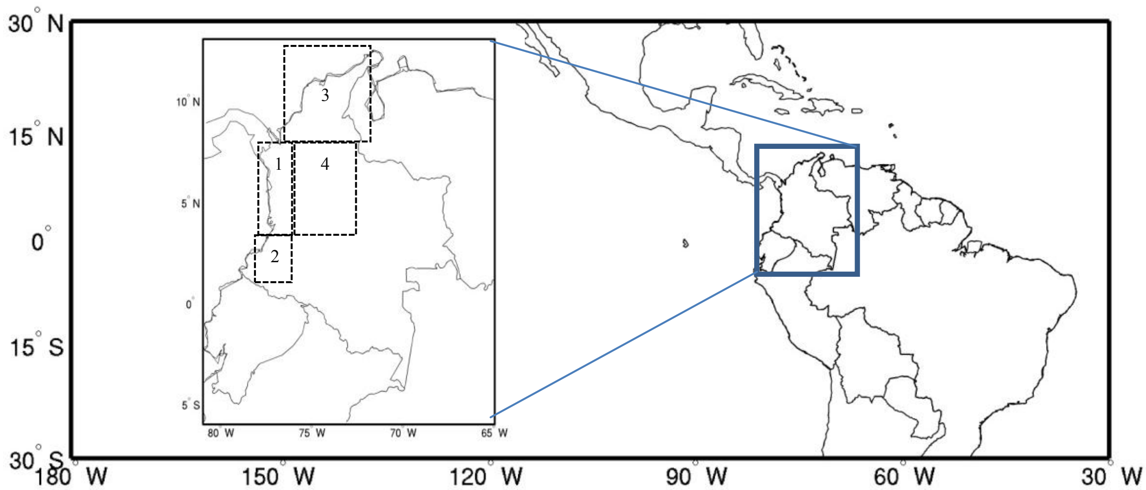

Fig. 1: Region used for the SLP analysis, Colombian precipitation area and selected regions for the precipitation study.

The model data used are that from the MIROC5 model, obtained from the Coupled Model Intercomparison Project (CMIP5), (Watanabe et al., 2010). The model data include historical atmospheric concentrations and future projections for representative concentration pathways (RPCs) RCP2.6, RCP4.5, and RCP8.5 (Moss et al., 2010; Taylor et al., 2012). The historical experiments cover from 1850 to 2005. In this study, the period 1971-2000 is used as representative of the present climate, while, for future climate the period 2071-2100 is considered.

3. METHOD

In this work the spatio-temporal variability of SLP reanalysis data from NCEP has been analyzed using principal component analysis (PCA). The main variability modes and their relationship with Colombian precipitation have been found by applying correlation analysis between the PCs of the SLP and the summer rainfall in Colombia. We use the non parametric bootstrap technique (Stine, 1985; Li and Smith, 2009) to assess the robust correlations between the main leading PCs and JJA rainfall. This is done by resampling, 1000 times, each PC series and the JJA rainfall with replacement, and then determining if the resulting correlation is significant. The regions with 95% of the 1000 resampled correlations significant at the 0.05 level are obtained.

When the significant PCs of SLP are selected, the PCR method has been applied to model the summer precipitation. The periods 1950-1993 and 1994-2010 were utilized as calibration and validation ones, respectively. The Bootstrap with replacement was applied to provide estimations of the statistical errors.

The ability of the MIROC5 model to simulate the summer precipitation in Colombia, for present climate (1971-2005), has been analyzed by calculating the differences between the simulated and observed precipitation values. Finally, in order to get summer precipitation projections in Colombia for the period 2071-2100, the downscaling model, recalibrated for the total period 1950-2010, has been applied to the SLP output from MIROC5 model under the RCP2.6, RCP4.5 and RCP8.5 scenarios.

4. RESULTS

4.1 SLP modes and relationship with precipitation

The leading modes of variability for seasonal JJA SLP values obtained from PCA of the reanalysis data in the period 1950-2010, explain 81.76% of the total variance. Figure 2 shows the spatial patterns (EOFs) of these modes.

EOF1 explains the majority (46.85%) of the variance in SLP, showing a spatial pattern that collets the variability of almost the whole tropical Pacific Ocean included in this study, with a positive correlation center located in the west of South America.

The second EOF, which explains 11.93% of the SLP variance, exhibits a more complex structure with positive and negative correlation centers. Figure 2 shows for this pattern high positive loading factors extending along Central and South America, together with another center of negative values located in the southwestern of the region under study.

EOF3 (8.56% of variance), exhibits two centers with opposite sign located at the Atlantic zone and the central tropical Pacific, respectively.

EOF4, EOF5, and EOF6 (6.47%, 4.13% and 3.82%, respectively) only account for a 14.43% of the SLP variance, and show different action centers over the region.

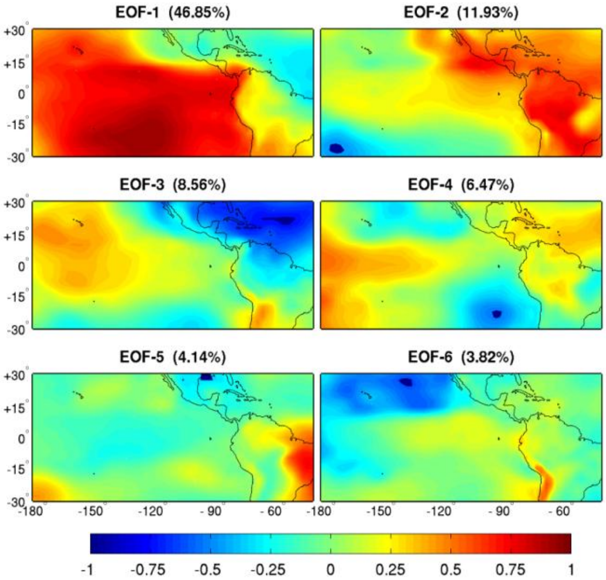

Fig. 2: Loading factors for the six variability modes of the summer SLP reanalysis data in the period 1950-2010.

The links between each of these SLP modes and summer rainfall is illustrated in Figure 3, which shows the correlations between individual gridpoint rainfall time series and each mode. The correlation map for PC1 shows a wide band of significant high positive values from the southwest to the north of Colombia, covering the Andes range. These positive correlations indicate that positive SLP anomalies are related to positive anomalies of precipitation. For PC2 the correlation map displays significant negative values located at the southwest, over the Andes Mountains, and the north of Colombia. Correlations for the PC3 present two opposite significant centers, sited to the north (positive) and to the south (negative), respectively. The correlation maps for PC4, PC5, and PC6 show disperse positive and negative low values over Colombia.

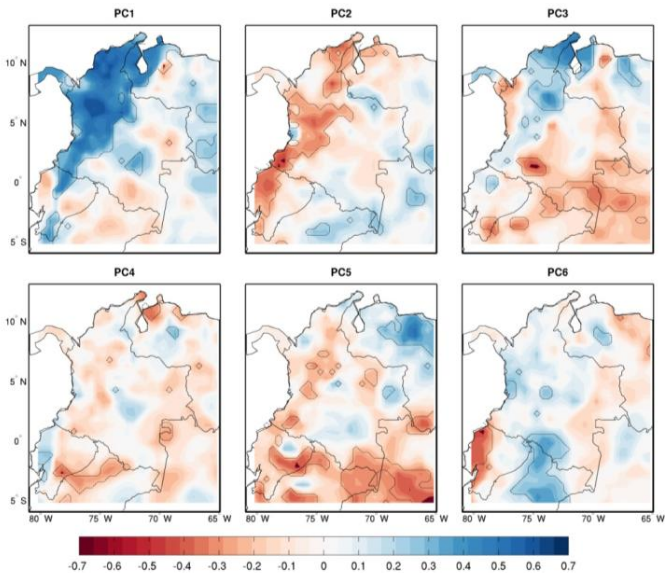

Fig. 3: Correlation patterns between JJA rainfall and the six leading PCs from SLP. Significant regions at 95% confidence level are contoured.

The relationships between the regional rainfall and the PCs from the SLP, have been analyzed by calculating the correlation coefficients after detrending the time series. The PC1 presents a strong link with the precipitation in all the regions, with significant values from 0.52 in the SWC region, to 0.70 in NC region. PC2 exhibits lower but significant negative values that reach -0.34 in the SWC region. However, the PC3 shows moderate significant values only with the precipitation of the NC and SC regions.

The results obtained highlight that only the first three variability modes of the SLP have a significant influence on the summer Colombian precipitation. So, only these three modes will be considered for the development of the downscaling models.

4.2 Principal component regression models for precipitation

Principal component regression (PCR) method is used to obtain the forecasting model for rainfall. For this analysis, we retain the first three modes (see Section 4.1) of SLP variability. The method for developing is calibration and validation, which uses the training period 1950-1993 as calibration period, and the period 1994-2010 to verify the model. The aim is to develop a robust model that provides a downscaled prediction for rainfall given a predicted large-scale SLP field.

Figure 4 shows the comparison between observed JJA rainfall amounts and the predicted for each of the four regions using the PCR models. The PCR skill models has been assessed by calculating the correlation coefficients (r) between the predicted and observed rainfall and the ratio of RMSE to the climatology of JJA rainfall (ρ). In general, there is a good performance of the models in the training period that is maintained or even increased during the subsequent verification period. All models perform reasonably well at the regional scales being the correlation values between predicted and observed series all highly significant at 95% confidence level. The values in the validation period range between r = 0.61 in the NWC region and r = 0.83 in the NCC region, and between ρ = 10.20 % in the NCC region and ρ = 16.15 % in the NC region.

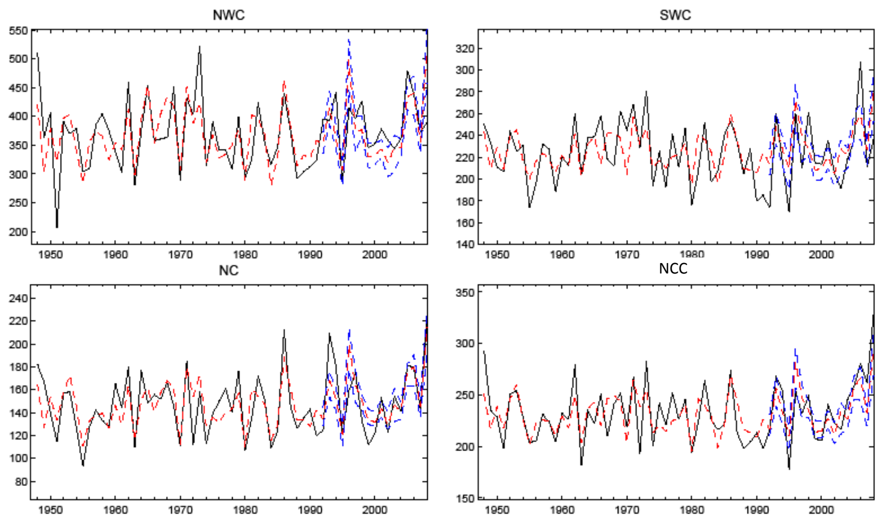

Fig. 4: Predicted (dashed red line) vs observed JJA rainfall amounts (black line) for each of the four regions. The results for 1950–1993 correspond to the training period, while the results for 1994–2010 correspond to the validation period. The dashed blue lines are upper and lower bands of the 95% confidence interval for the verified predictions estimated using 1000 bootstrap replications.

To detect where this downscaling technique is most useful, we have also used the gridded rainfall data, and the correlations between observed and predicted rainfall in each point of the grid have been computed. Figure 5 provides an illustration of the relative contribution of each of the three PCs of the SLP to PCR models for the estimations of the gridded summer rainfall totals. The spatial distribution of the correlation coefficients (Fig. 5) shows high values (between 0.5 and 0.93) along Andes range, north and north Pacific of Colombia.

4.3 Application to climate change simulations

We apply the downscaling models to SLP data derived from the MIROC5 model simulations for both the present (1971-2000) and future (2071-2100) climate under the RCP2.6, RCP 4.5 and RCP8.5 scenarios.

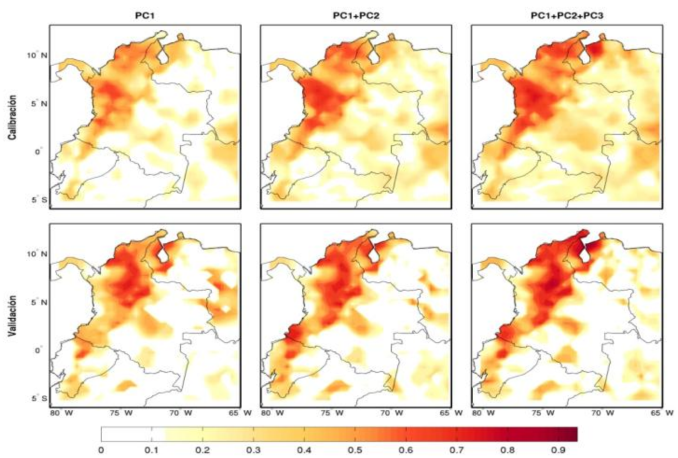

Fig. 5: Spatial distribution of the correlation coefficients between observed and predicted rainfall in each grid point estimated by PCR models using the PC1, PC1+PC2, and PC1+PC2+PC3 of the SLP, for calibration and validation periods.

Figure 6 presents the observed precipitation field and the estimated from the downscaling method in the calibration period (1950-1993, Fig. 6a and Fig. 6d, respectively) and in the validation period (1994-2010, Fig. 6b and Fig. 6e, respectively). The simulated precipitation by the MIROC5 model and the estimated by the SD model applied to the SLP of this GCM, are also shown in Figure 6c and Figure 6f, respectively, for the common period 1971-2000. In general, the PCR models fairly good simulate the precipitation in Colombia, for both calibration and validation periods. The simulation obtained by the GCM strongly overestimates the precipitation along a horizontal sector through the center of Colombia, specially important at the east and west of the country. However, the SD model applied to the SLP of the GCM, shows its ability to faithfully reproduce the rainfall field.

In order to identify the potential impact of the climate change, the results obtained by applying the SD models to the SLP of MIROC5 under the RCP2.6, RCP4.5 and RCP8.5 scenarios are shown in Table 1 for each of the regions. The results indicate that the SD summer precipitation represent fairly good the observed precipitation (1971-2000), showing no significant differences, below 3% in most cases. However, the GCM simulation presents a significant overestimation around 51%, 55%, 139% and 72% in the NWC, SWC, NC and NCC regions, respectively.

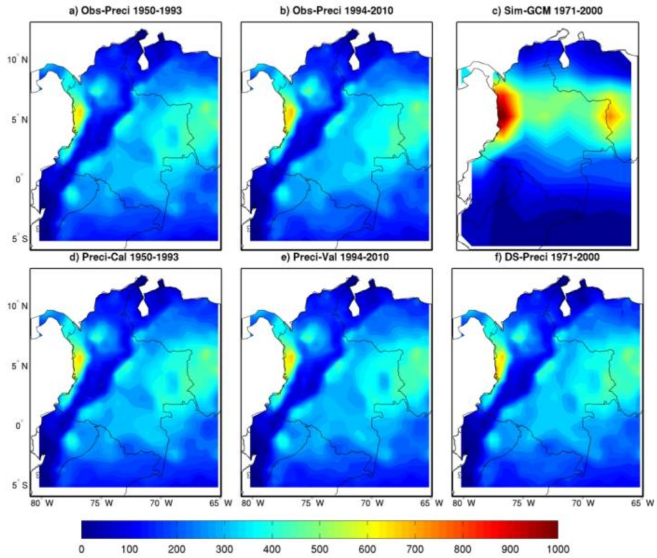

Fig. 6: Spatial distribution of a) observed and d) estimated precipitation (in mm) during the calibration period. The same for the validation period, b) observed precipitation, e) estimated precipitation by SD model. c) Simulated precipitation by MIROC5 model, and f) simulated precipitation by SD model applied to the SLP of MIROC5, during the period 1971-2000.

	1971-2000			2071-2100					
	(mm)	Diff. (mm)	Diff. (%)	RCP2.6 (mm)	Diff. (%)	RCP4.5 (mm)	Diff. (%)	RCP8.5 (mm)	Diff. (%)
NWC region									
Obs.	368.66								
GCM	557.11	188.45	51.12	565.05	53.27	562.69	52.63	565.55	53.41
SD NCEP	368.75	0.09	0.02						
SD GCM	367.72	-0.95	-0.26	376.78	2.20	424.66	15.19	443.18	20.21
SWC region									
Obs.	223.77								
GCM	347.69	123.92	55.38	357.56	59.79	360.99	61.32	370.13	65.41
SD NCEP	223.15	-0.62	-0.28						
SD GCM	220.47	-3.30	-1.48	218.76	-2.24	237.76	6,25	242.55	8.39
NC region									
Obs.	146.06								
GCM	348.46	202.40	138.57	334.18	128.80	334.48	129.00	323.20	121.28
SD NCEP	145.77	-0.29	-0.20						
SD GCM	150.93	4.87	3.34	150.75	3.21	175.96	20.47	185.82	27.22
NCC region									
Obs.	230.29								
GCM	395.29	164.99	71.65	366.73	59.25	358.95	55.87	347.49	50.89
SD NCEP	231.74	1.44	0.63						
SD GCM	235.79	5.50	2.39	235.57	2.29	260.99	13.33	270.60	17.50

TABLE 1: REGIONAL MEAN JJA RAINFALL SHOWING A COMPARISON BETWEEN OBSERVED, GCM SIMULATED, AND DOWNSCALED PRECIPITATION VALUES,

FOR BOTH THE PRESENT (1971–2000) AND FUTURE (2071–2100) PERIODS UNDER THE DIFFERENT CLIMATE CHANGE SCENARIOS.

The changes estimated by the SD models in the future are not significant under the RCP2.6 scenario, while for the RCP4.5 and RCP8.5 scenarios a significant increase of precipitation appears regard to the observed values at present in all the regions, reaching around the 27% in the NC region under the RCP8.5 scenario. Whereas the forecasted values by the GCM show an increase that reach 129% in the NC region, under the RCP4.5 scenario, with light differences respect to observed values between different scenarios. For the case of precipitation gridded data, the results are in accordance with the obtained from the regional study.

5. CONCLUSIONS

In this study a statistical downscaling method has been developed to obtain the summer precipitation in Colombia using the SLP as predictor variable. The PCA applied to the seasonal JJA SLP reanalysis data from NCEP show the existence of six leading variability modes that account for an 81.76% of the variance. The analysis of the correlations between their corresponding PCs and the summer precipitation in each gridded point and in each region, shown that only the first three modes (67.34% of the variance) have significant influence (at 95% confidence level) on summer Colombian precipitation, so the first three PCs were considered for the development of SD models. The PCR skill models show a good performance with correlations coefficients between 0.5 and 0.93 along Andes range, north and north Pacific of Colombia in the validation period, and regionally, between 0.61 in the NWC region, and O.83 in the NCC region.

The summer precipitation in Colombia calculated from SD models applied to the SLP data derived from the MIROC5 model, has been compared with the observed and the forecasted values by the GCM model in present climate (1971-2000). This comparison clearly shows that the simulation obtained by the GCM strongly overestimates the precipitation along a horizontal sector through the center of Colombia, specially important at the east and west of the country. However, the SD model applied to the SLP of the GCM, shows its ability to faithfully reproduce the rainfall field.

The changes estimated by the SD models in the future (1971-2100) under different scenarios are not significant under the RCP2.6 scenario, while for the RCP4.5 and RCP8.5 scenarios a significant increase of precipitation appears regard to the present values in all the regions, reaching around the 27% in the NC region under the RCP8.5 scenario. Whereas the forecasted values by the GCM show an increase that reach 129% in the NC region, under the RCP4.5 scenario, with light differences respect to observed values between different scenarios. For the case of precipitation gridded data, the results are in accordance with the obtained from the regional study.

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