INFLUENCE OF TROPICAL PACIFIC SST ON SEASONAL PRECIPITATION IN COLOMBIA. PREDICTION USING EL NIÑO AND EL NIÑO MODOKI

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ABSTRACT

In this paper the forecast skill provided by the tropical Pacific SST associated with El Niño and El Niño Modoki over seasonal precipitation (Pt) in Colombia has been evaluated through a lagged Singular Value Decomposition analysis. This analysis has been made based on the results in a companion paper where the impact of El Niño and El Niño Modoki over the seasonal precipitation in Colombia was analyzed and quantified. The seasonal rainfall in many parts of the country can be predicted with good skill using the SST with a lead of one to four seasons. Winter presents the best results for the prediction model, explaining the greatest percentage of square covariance fraction between the SST and lagged precipitation anomalies. The predictive capacity of these variability modes of SST for rainfall in Colombia is comparable or even higher in some seasons, particularly in winter, that the ability of these modes to explain the behavior of the precipitation during coetaneous seasons. The forecast of seasonal precipitation in Colombia validated in this work could be useful for planning and managing natural water resources in this country.
Keywords: Seasonal precipitation forecast, Tropical Pacific SST, El Niño, El Niño Modoki, Colombia.

RESUMEN

En este estudio se evalúa la capacidad de predicción que posee la SST del Pacífico tropical asociada con los fenómenos El Niño y El Niño Modoki sobre la precipitación (Pt) estacional en Colombia, a través del Análisis de Descomposición del Valor Singular. Este análisis está soportado en los resultados obtenidos en un artículo complementario donde ha sido analizado y cuantificado el impacto de El Niño y El Niño Modoki sobre la precipitación estacional en Colombia. La variabilidad de la Pt estacional en muchos lugares del país se puede predecir con una buena habilidad usando la SST desde una y hasta cuatro estaciones anteriores. Para la estación de invierno se explica el mayor porcentaje de la fracción de covarianza cuadrada entre las anomalías de la SST de estaciones anteriores y las anomalías de Pt. Además, en esta estación se obtienen los mejores resultados del modelo de predicción. La capacidad predictiva de los dos primeros modos de la SST sobre la Pt en Colombia es comparable o mayor en algunas estaciones, que la habilidad que tienen estos modos para explicar la variabilidad de la Pt durante estaciones coetáneas, principalmente para la estación de invierno. La predicción estacional de la Pt, desarrollada en este estudio podría ser de utilidad para la planificación y el manejo de los recurso naturales en el país.
Palabras Claves: Predicción estacional, precipitación, SST del Pacífico Tropical, El Niño, El Niño Modoki, Colombia.

1. INTRODUCTION

The predictions concerning different hydro-climatic variables (precipitation, streamflow, temperature, wind, etc.) are of great importance for the planning, using, and managing natural resources of a country as well as for the preventing and attending natural disasters caused by extreme phases of climate variability. Good climate prediction can help reduce negative impacts on human populations (outbreaks of diseases, loss of human lives, etc.), and allows managers to take advantage of favorable conditions to strengthen the socio-economic development of a region, through proper planning of the future.

Many studies have reported evidence of the strong relationship and the important predictive ability of the tropical Pacific Sea Surface Temperature (SST) variability over the precipitation in many regions of the world (e.g., Ropelewski and Halpert, 1987, Taschetto and England 2009; Li and Chen 2013; Tedeshi et al., 2013), explaining various physical mechanisms of coupling between these variables, linked mainly with El Niño/Southern Oscillation (ENSO). Another important ocean-atmosphere pattern of variability has recently been demonstrated in the tropical Pacific Ocean, called El Niño Modoki (ENM, Ashok et al. 2007), which significantly influences the climate of various regions of the planet (Weng et al. 2007, 2009) and could be used as an additional predictor that contributes to explain the variability of precipitation in diverse regions of the world (Weng et al. 2011; Córdoba-Machado et al. 2014).

For Colombia, several studies have shown the strong influence that the SST of tropical Pacific associated with El Niño/La Niña (EN/LN) exerts over hydro-climatic variables such as precipitation, streamflow or temperature (Tootle et al. 2008; Poveda et al. 2011; Gutiérrez and Dracup 2001; Pabón and Montealegre, 1992). However, only a few studies quantify the influence of ENM on the climate of this country and analyze its predictive skill. Recently, some works (Weng et al. 2007; 2009; Ashok et al. 2007; Tedeschi et al. 2013) have revealed that ENM has significant impact on the rainfall variability over South America, showing the importance of this phenomenon on the climate of various countries in the region. Córdoba-Machado et al. (2014) quantified the impact of the tropical Pacific SST on seasonal precipitation of Colombia through of the two main modes of variability, essentially associated with EN and ENM.

Given the importance of ocean-atmosphere coupling patterns on regional climate variability in Colombia, the main objective of this study is to evaluate the seasonal precipitation forecasting skill attributable to EN and ENM. For this, a study has been carried out, analyzing the relationships between the seasonal tropical Pacific SST and seasonal Pt in Colombia when SST leads on time.

This study is structured as follows: Data and methodology are presented in Section 2, Section 3 describes the main results, and Section 4 presents the conclusions.

2. DATA AND METHODOLOGY

The datasets used in this study include the monthly SST from HadISST (Rayner et al. 2003), and the monthly precipitation data set for Colombia described in the Córdoba-Machado et al. (2014), provided by the institute of Hydrology, Meteorology, and Environmental Studies of Colombia (IDEAM), for the period 1979-2009. For all the fields, anomalies have been computed by subtracting the respective means during this period. El Niño Modoki index (EMI) is defined following Ashok et al. (2007), while the canonical El Niño (EN) is quantified by the Niño3 index (see Córdoba-Machado et al. (2014), All the statistical significance tests are performed using Student's two-tailed t test.

A SVD analysis with the seasonal Pacific SST field leading the seasonal Pt in Colombia (lagged SVD hereafter) has been used to reconstruct and predict the precipitation in this country, during the period 1979-2009. The SVD analysis is an advisable technique when the predictor field and the field to predict are connected with teleconnection patterns (Bretherton et al., 1992; Björnsson and Venegas, 1997). This methodology has two stages: the reconstruction algorithm (Wei et al. 2012), and the prediction algorithm (Liu 2003).

During the reconstruction process through the SVD analysis, the seasonal SST is used as the predictor variable for the seasonal Pt in all the seasonal couplings of the lags employed (of 1 to 4 seasons). Following the methodology used by Weit et al. (2012), we can reconstruct the original field of Pt: (1) a linear regression model is constructed between the first m coefficients of expansion associated to the SST and Pt modes, with the aim of reconstructing the first m coefficients of Pt, as a function of the first m coefficients of SST; and (2) these reconstructed expansion coefficients are used to establish the reconstructed field of Pt (Weit et al. 2012). In this study, we have used the first two modes, $m = 2$.

As in the reconstruction algorithm, during the prediction process a model is constructed for the precipitation, $P(t + n, x)$, of the following seasons (from $n = 1$, to $n = 4$ seasons), being determined mainly by the expansion coefficients, $CS(t)$, of the SST in the current season, and the variability modes of Pt, V, obtained through the lagged SVD analysis. The following steps are performed to configure the prediction model through the lagged SVD: (1) From the original data matrices $SST(t,x)$ and Pt($t+n,x$) the validation matrices, SSTval(t,x) and Ptval($t+n,x$) are constructed by removing the data of the yth year (with $y = 1, 2, ..., Y$, $Y = 31$ when the SST and Pt seasons correspond to the same year, and $Y = 30$, when the Pt season belongs to the following year). The calibration matrices SSTcal(t,x) and Ptcal($t+n,x$) have the remaining data in the original data matrices. This method is usually called *leave one out;* (2) a lagged SVD analysis between the calibration matrices is applied; (3) the expansion coefficients of SST for the validation period, are obtained projecting the SSTval on the SST mode that result in step 2; (4), the regression coefficients between the expansion coefficients of the two fields for the calibration period are determined using least squares approximation, and the precipitation for the validation period, is obtained projecting the Pt expansion coefficients, on the *Pt mode.* Finally, (5) the previous steps for each of the matrices (validation and calibration) created through the *leave one out* method (from $y = 1$ to Y) are repeated, generating Y predictive models for each seasonal lag established between the two fields of variables. For more details, of prediction process see Liu (2003). The skill of the prediction process is evaluated through the expected error (RE) between the predicted Pt series and the original Pt series.

3. RESULTS

The results of applying the lagged SVD methodology between the SST anomalies in the tropical Pacific and the Pt in Colombia, when SST is leading Pt between 1 and 4 seasons, reveal the dominant coupled modes of variability between the two fields. Figure 1 show the first mode derived from this analysis. For all figures shown in this paper, the first acronym (DJF\, MAM\, JJA\, or SON\) indicates the chosen season of the year for the SST, while the second acronym (\DJF, \MAM, \JJA or \SON), indicates the season for lagged Pt. The term +1 in the maps indicates that the seasonal Pt corresponds to the following year of the seasonal SST. The first mode corresponding to the SST (Fig. 1a), in general, clearly represents the pattern associated with EN (Ropelewski and Halpert, 1987), characterized by negative anomalies in the western Pacific Ocean and a significant anomalous warming over the eastern equatorial Pacific Ocean, extending from the coast of South America to the central Pacific region. The square covariance fraction (SCF) coupled between the two fields varies between 45% (JJA\MAM+1) and 94% (SON\DJF+1), according to the lag and the seasons of year used. Thus, the coupling between the autumn SST (SON\) and winter Pt of the following year (\DJF+1), registers the highest percentage of explained square covariance fraction (94%) between the two fields.

The correlation between the SST expansion coefficients and the Pt expansion coefficients provide values ranging from 0.58 (MAM\DJF +1) to 0.83 (JJA\SON) (Fig. 2), this latter being the maximum strength coupling (SC) that exists in all the lags between these two fields. All correlation values found are significant at 95% confidence level. Moreover, the correlation coefficient between the SST expansion coefficients and the Niño3 index is highly significant, exceeding the value of 0.84 in all cases. The time series of expansion coefficients of the SST and Pt, are dominated by interannual oscillations (figure not shown).

The second mode determined from the lagged SVD analysis (Fig. 1b) is not as stable as the first one, showing marked differences in the SST patterns. In general, the second mode shows a structure associated with ENM (Ashok et al. 2007), which is characterized by a nucleus of positive SST anomalies in the central Pacific Ocean (shifted westwards), bordered by negative SST anomalies on both sides of the Pacific, over the east (near the coast of South America) and the west (near the coast of Australia), thus drawing a boomerang-shaped or horseshoe structure over the tropical Pacific Ocean. The square covariance fraction (SCF) ranges from 3.3% (SON \ DJF +1) and 23% (MAM \ MAM +1), depending on the lag and the seasons used for the SST and Pt, while the covariance fraction (CF) has values between 9.6% (DJF \ DJF +1) and 18% (JJA \ DJF +1). This mode, despite being less important for the variability of Pt in Colombia, shows a large coupling force between the SST and Pt fields, giving significant correlation values, which vary between 0.58 (MAM \ DJF) and 0.83 (DJF \ MAM), depending on the lag and the season of year used. The correlation coefficients between the SST expansion coefficients and the EMI, provide values from 0.6 (JJA/DJF+1) to 0.97 (SON/SON+1). All correlations are significant at the 95% confidence level.

The heterogeneous correlation maps reveal the important influence of the first mode of variability of the tropical Pacific SST over the variability of the Pt in later seasons for different localities (Fig. 2a). Correlations are all above the 95% significance level and it is observed that the values of significant correlations persist and even increase the number of localities influenced, depending of the lag.

This result reveals the important potential predictability of the seasonal Pt in Colombia based on the EN phenomenon. Also the persistence of this SST pattern is remarkable over all the seasons of the year, regardless of lag, showing a relative stability of its predictive power. During winter, Pt shows the maximum number of localities with significant correlations (Fig. 2a, maps on the diagonal from the lower left edge –SON\DJF+1, to the upper right edge, –DJF\DJF+1), these being most influenced by the SST of the previous seasons. Also, depending on the lag, increases (positive correlations) or decreases (negative correlations) of Pt are found in many localities of Colombia, mainly in center, west, and north of the country. Generally for 1 lag season, the influence of SST over the Pt tends to be the opposite of the influence that occurs when there is 4 seasons of lag (1 year).

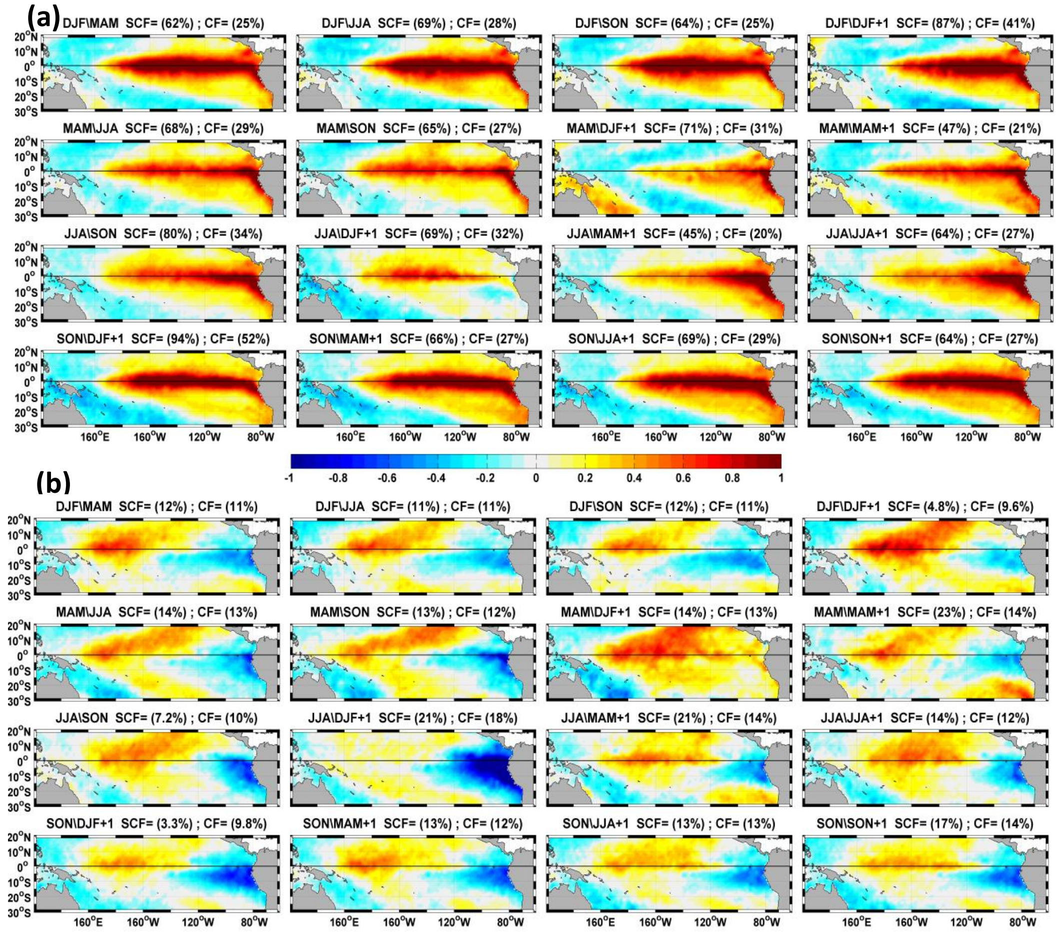

Fig. 1: (a) First and (b) second mode of the tropical Pacific SST derived from lagged SVD analysis between the SST and the Pt seasonal anomalies in Colombia, during 1979-2009.

The heterogeneous correlation maps (Fig not shown) show that the second mode of the tropical Pacific SST (ENM) during winter is associated with a decrease of Pt in some localities of Colombia during the four following seasons. In spring this decrease occurs in the three following seasons and then, during the fourth season, is linked with greater rainfall over central and north of Colombia (MAM Pt of the following year). Finally, during summer and autumn, ENM mode presents significant correlations with the seasonal Pt of the following 4 seasons, autumn being the mode registering the maximum number of localities with negative correlation values (decreased rainfall associated to the positive phase of ENM). The summer SST shows significant positive correlations with the following spring Pt, in several localities in the center and north of the country. Like the first mode, the influence of this second SST mode over the Pt in Colombia persists for several seasons, showing a strong predictive capacity.

3.1 Reconstruction

The Figure 2 presents the correlation maps between the original Pt series and the reconstructed Pt series through partial regression analysis, using the expansion coefficients corresponding to the first two modes of the tropical Pacific SST determined in the lagged SVD analysis, for one to four season lags. Only correlation values above 0.5 are shown.

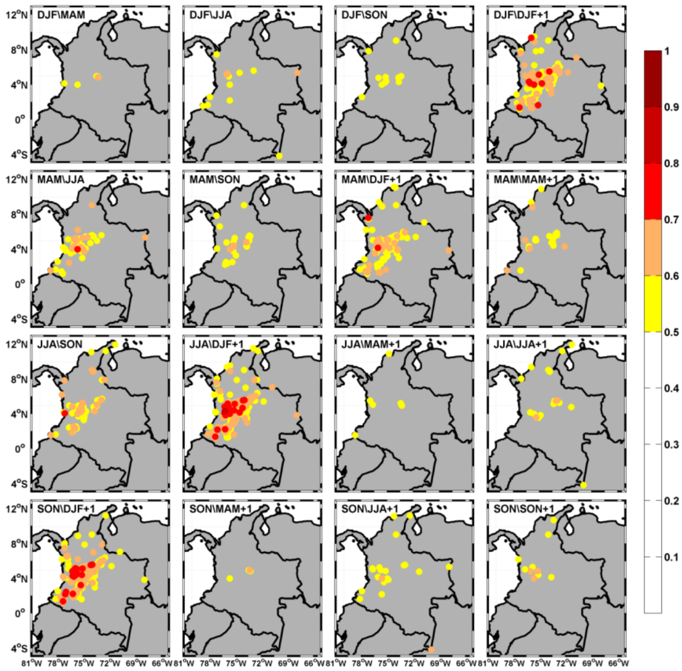

Fig. 2: Correlation coefficients between the original and reconstructed series of Pt through the partial regression analysis, using the expansion coefficients of the first two mode of the SST (EN+ENM), calculated from lagged SVD. Only values greater than 0.5 are displayed.

Firstly, the reconstruction of the original Pt series using only the first mode of the tropical Pacific SST (EN) has been performed (figure not shown). Although for many cases high correlation values occur, for some cases as DJF\SON; JJA\MAM+1; SON\MAM+1; SON\JJA+1; SON\SON+1, no locality exceeded the threshold.

Comparing this reconstruction with the one found using the two first modes (EN and ENM) (Fig. 2), we find a significant increase both in the value of the correlations between the original series and the reconstructed series, as well as in the number of localities that exceed the correlation threshold of 0.5. These results reveal the important role that the ENM pattern plays in the reconstruction of the Pt in Colombia. Additionally, the Figure 2 (maps in the diagonal from the lower left –SON\DJF+1, to the top right –DJF\DJF+1) reveals that winter, is the season that presents the best results for the reconstructed Pt series, recording the highest correlation values and the largest number of localities with correlations exceeding the value of 0.5. The spring Pt shows the worst reconstruction, recording the lowest number of localities with correlations above 0.5. All correlation values are significant above the 99% confidence level.

Overall, the root mean square error between the original Pt series and the reconstructed ones, shows higher values in the western region of Colombia [this region is considered one of the rainiest on Earth, Eslava, 1994], reaching values between 80 and 100 mm and the localities in central and northern Colombia typically have errors ranging between 10 and 70 mm. Although the first mode of variability of the tropical Pacific SST (EN) is the mode that exerts the greatest impact on the seasonal Pt of Colombia, the second SST mode (ENM) over the variability of the Pt in the following seasons, showing a significant contribution for the reconstruction of original seasonal Pt series in Colombia with some seasons in advance.

3.2. Prediction

Given the ability shown by the distribution of the tropical Pacific SST associated with EN and ENM to reconstruct the Pt in Colombia with several seasons in advance, a forecast experiment was performed to predict the seasonal Pt using the leave one out method in the lagged SVD analysis. The Figure 3 shows the correlation maps between the original seasonal Pt series and the forecasted Pt series, for those seasonal lags that present at least one locality with correlation value above 0.5. Furthermore, only locations where the expected error is higher than zero {RE > 0} are plotted.

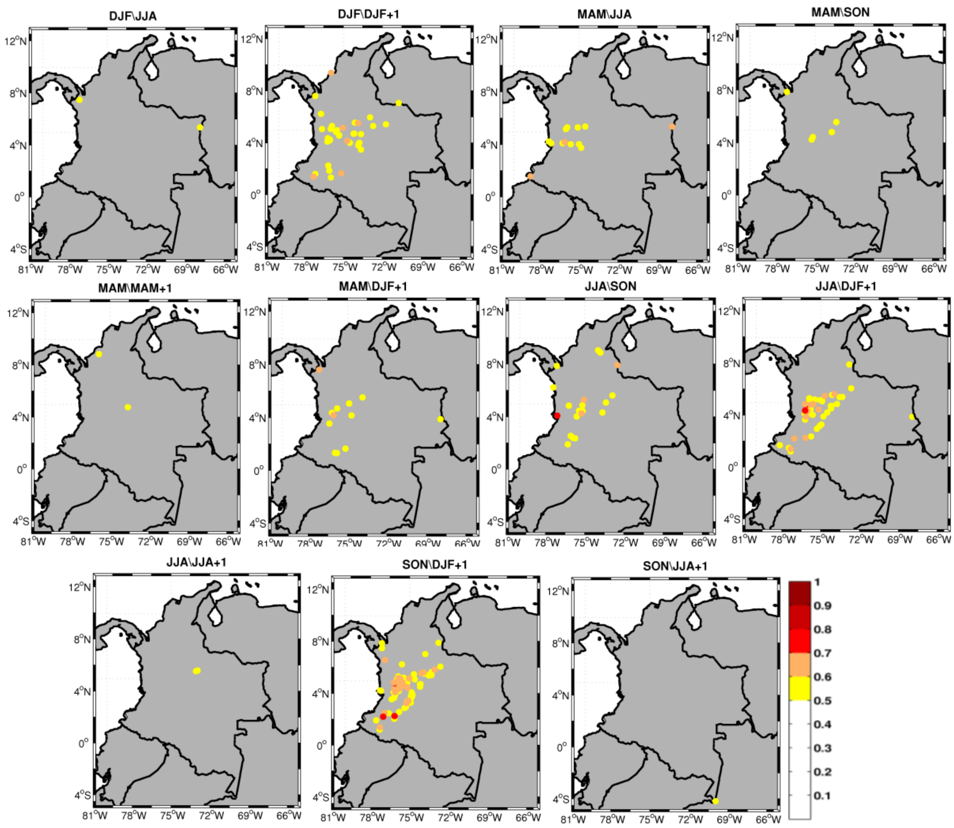

Fig. 3: Correlation maps between the original and forecasted Pt series. Only the localities where the correlation is greater than 0.5 and the expected error is greater than zero {RE > 0} are plotted.

The Pt during spring is the worst explained using this prediction scheme, independently of the seasonal SST that is used as the predictor variable. However, winter Pt (\ DJF) shows an important number of localities with significant correlations above 0.5, when we use the expansion coefficients associated with the first two modes of SST for the SON (SON \ DJF +1, i.e. a prediction for one season in advance), JJA (JJA \ DJF +1, for two seasons in advance) or DJF (DJF \ DJF +1, for a year in advance) as the predictor, indicating that winter

Pt could be predicted, up to a year in advance, for many locations of Colombia. These localities are generally placed in the center, southwest, and northeast of the country. Note that using spring SST (MAM \) as predictor, we can explain a significant portion of the Pt at various locations in Colombia during the following 4 seasons, mainly for summer Pt. Also it is important to note that in spring, the second coupled mode between the Pt in Colombia and the SST of tropical Pacific, associated with ENM, gains greater importance while the predominant SST mode, associated with EN, is less important, considering the square covariance fraction explained by the modes in other seasons of year. These results demonstrate the great capacity of the distribution of the tropical Pacific SST (linked to the two types of El Niño) in previous seasons to predict seasonal Pt in Colombia, mainly for winter. The root mean square error between the original Pt series and the predicted Pt series, for each locality, shows acceptable values, taking into account the seasonal rainfall regime in each region. The lowest values (20 to 60 mm) usually occur over central Colombia, while the highest values (> 80 mm) are recorded in the west of the country.

The forecasted Pt series generally provide a good representation of the interannual variability of the original Pt series. Figure 4 shows several time series of the original Pt in winter (DJF +1) and the predicted Pt series in the same season, using the two first variability modes of SST during the preceding autumn. The correlation values between the series are above 0.64 and the error below 0.31. The localities of these series are situated on the center and southwest of the country (SON\DJF+1 in Fig. 3). From the results, we conclude that the predicted series considerably explains the temporal variability of Pt in Colombia, demonstrating the good skill of the prediction model used.

4. CONCLUDING REMARKS

This paper evaluates the skill provided by the tropical Pacific SST associated with the two types of El Niño (EN and ENM) to predict the seasonal precipitation in Colombia. The results show that the seasonal rainfall in many parts of the country can be predicted, with a good skill, using the SST with a lead of one to four seasons. Winter is the season that presents the best results for the prediction model, also being the season where the coupled modes, found through lagged SVD analysis, explain the greatest percentage of square covariance fraction between the SST and Pt anomaly fields.

The variability of SST associated with the EN phenomenon is the most important pattern for explaining the seasonal precipitation variability in Colombia, while ENM is the second best variability mode of tropical Pacific SST that influences the seasonal rainfall of the country. Previously Poveda and Mesa (1997) used a principal component analysis to show that the pattern associated with EN phenomenon is strongly linked with the hydro-climatology in Colombia. Similarly, Tootle et al. (2008), using the SVD between the streamflows series of several major rivers of the country and the SST of Pacific Ocean, Pacific and Atlantic (together), and Atlantic Ocean separately, concluded that the first variability mode of SST, both in the Pacific and in the Pacific / Atlantic, reflect the ENSO variability and are significantly related with the streamflows. However, these authors did not refer to the influence that the second variability mode of tropical Pacific (ENM) could have on the country. This influence, evidenced in Córdoba-Machado et al. (2014) and in the present work shows the improvement achieved by considering ENM to explain and reconstruct (/ predict) the seasonal precipitation in the country. It is important to note that the predictive capacity of these variability modes of SST in rainfall of Colombia is comparable or even higher in some seasons (e.g. winter) compared with the ability of these modes to explain the behavior of the precipitation during coetaneous seasons (Córdoba-Machado et al., 2014). A noteworthy aspect concerning the analysis of potential Pt predictability in Colombia from SST patterns with several season lags is the fact that the correlations change sign. This may be related to the periodicity of the variability modes of SST analyzed (Kestin et al., 1998).

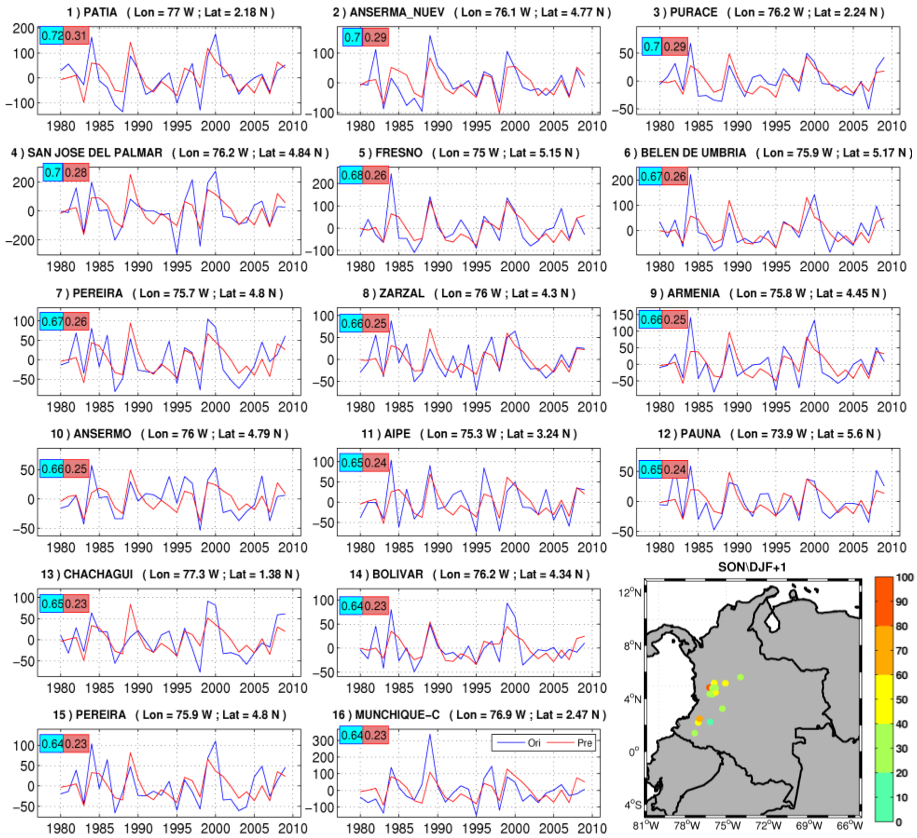

Fig. 4: Original (blue) and predicted (red) Pt series in winter, using the first two modes of the SST in previous autumn. Blue and red boxes indicate the correlation between the two series and the expected error, respectively. The map shows the location and the mean square error between the series

The results found in the present study, contribute to the improvement of prediction models for the precipitation in Colombia and could be very useful for institutes linked to the planning and the management of natural water resources of this country.

In summary, the results presented involve not only predictions for seasonal Pt in Colombia through prior knowledge of the field of SST in the tropical Pacific, but they may also be used as a basis for other types of studies such as the analysis of impact of climate change in Pt at the regional scale from the use of adequate predictors to be included in statistical models.

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