Impact of El Niño Phenomenon, Southern Oscillation (ENSO on Hydrometeorology Variability at Valle del Cauca State, Colombia, Using Canonical Correlation Analysis

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Abstract. The linear teleconnections between the ENSO phenomenon and Valle del Cauca State, Colombia (Colombia) monthly inter annual and seasonal hydro meteorological, were studied. Two multivariate statistical techniques were used: Empirical orthogonal functions (EOFS) and the canonical correlation analysiss (CCA). The ENSO effect is higher on flows that on precipitation. It was concluded that in March-April-May (MAM) and September-October-November (SON) periods the ENSO association and effect on regional hydrometeorology is lower; while, in December-January-February DJF and June-July-August (JJA), the effect is higher. The inclusion of principal components of macroclimatic variables such as variables predictors for the precipitation and flows models improved the prediction, indicating that they contribute with additional information. The flow models showed good fit and they can be used for prediction. Likewise, the multivariate EOFS and CCA methods proved to be valuable tools in the study of climate variability so as to understand the relationships between ENSO phenomenon with the region hydro meteorological regime.

1 Introduction

Valle del Cauca State, Colombia region is one of the most affected areas by the climatic variability associated to ENSO given its proximity to the Pacific Ocean. In Colombia; the warm phase of ENSO is associated to droughts, forest fires, interruption of electricity supply, reduction in agricultural, fishing, and cattle production, (Carvajal et al, 1998); as well as increase in the cases of malaria and endemic illnesses. The cold phase (La Niña) is associated with human lives losses due to natural disasters, land slides, flush flows, and floods, as well as erosion and a remarkable increment in sediments transport by rivers.

ENSO has a great socioeconomic impact in the country, which has not been sufficiently studied, and it is still open to evaluation, is important to consider this topic, including the macroclimatic variables associated to ENSO for water resources planning, agricultural production studies, forest fires, health,

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etc. These variables have to be incorporated to the management processes of natural resources, through a multisectorial integration and a holistic vision in order to adopt sustainable strategies. This work aims at analysis the hydro meteorological variability at Valle del Cauca State, Colombia - Colombia region, by applying Canonical Correlation Analysis (ACC), with the purpose to evaluate the association with the phenomenon, and to offer better judgment elements to be used by water resources planners at regional level.

2 Data and Methodology

Nine macroclimatic variables associated to ENSO were used: superficial temperature of the Pacific Ocean in the regions: Niño 1-2, Niño 4, west coast of United States, Cold Tongue index, exterior long wave radiation, wind speed in the west Pacific Ocean, atmospheric pressure in Darwin-Australia, South Oscillation index, and the ENSO multivariate index, obtained from (COADS-NOAA), monthly precipitation of 50 raingauge stations (1972-1998) and monthly discharge data from 8 measuring stations (1951-2000), located on the Cauca (7) and la Vieja (1) Rivers, at Valle del Cauca State, Colombia Colombia, were used. The records were previously tested in a quality control process which included the data adjustment for the flows of the Cauca River from 1985, when the Salvajina dam started its operation. The precipitation series were classified in 3 homogeneous groups corresponding to 20, 25 and 5 meteorological stations by using hierarchical cluster analysis being verified by geographical methods and discriminate analysis of the first 4 FOES of precipitation, (Carvajal & Marco, 2003).

Taking into account the bimodal behavior of the precipitation and the discharge in the region, the standardized series were previously divided in quarterly: Dec-Jan-Feb (DEF), Mar-Apr-May (MAM), Jun-Jul-Aug (JJA) and Sep-Oct-Nov (SON), corresponding to two dry periods and two humid ones in alternated way. As previous step to ACC, analysis FOES was carried out on all of the variables groups, with the purpose to compact the essential information, eliminate the multi-co lineal and reduce the small scale noise. The PC analysis or FOES, is a multivariate statistical technique consisting in to obtain dominant patterns for the group variability of variables, projecting the series in the orthogonal spatial patterns (eigenvectors or FOES) to obtain the time associated coefficients (PC). The principal components (PC) that take in to account the biggest variances generally are the most significant while the smallest variances are discarded as statistically and physically insignificant (noise), Preisendorfer and Barnett (1987). For the selection of the number of significant PC, 7 methods were used, of those which, cross validation was chosen as the best, given that it is the most analytic and of the major computational requirement, (Carvajal and Marco, 2003). Five PC of macroclimatic variables were selected, 4 of the flows group, and for the whole precipitation group and the homogeneous groups 1, 2 and 3, were selected, 4, 1, 2, and 1 PC's, respectively. After this, ACC was carried out between the principal components of the macroclimatic variables versus precipitation and

flows in separated way. ACC, considered as hierarchical top for the regression models, is a multivariate statistical procedure, by which the lineal combinations of variables for a predictor set are optimized; this set explains the biggest variance in another set of dependent variables. The methodology has been widely used in analysis of climatic variability and it can be used in prediction, (Von Storch and Zweirs, 1999). Barnett and Preisendorfer (1987) propose to filter the field series with an EOFS decomposition before to enter the ACC and carry out the calculation in EOFS coordinates. Several reasons exist to do this: the noise of the data is filtered when the FOES series are truncated. In the FOES ´s space the field coordinates are the PC's, and when the standardized PC is used, the auto covariance matrix M_x and M_y are symmetrical, and consequently, they are equal to the identity matrix, simplifying the calculations vastly. Finally, the prediction model for each analysis was validated for the independent precipitation periods 1988-1998, and the 1990-2000 one for flows by using a multivariate model, whose parameters were defined by the coefficients for the calculated canonical components.

3 Results and discussion

3.1 Seasonal canonical correlation analysis. The Table 1 summarizes the canonical correlations obtained, for the different analysis. The statistical significance of these correlations was evaluated applying bootstrap for 1000 samples, exchanging successive pairs of canonical coefficients, (Efron, 1982)

Table 1. Canonical correlations obtained by different ACC between the principal components of macroclimatic variables vs monthly precipitation and discharge

CC	DEF	Sig	MAM	Sig	JJA	Sig	SON	Sig	ANUAL	Sig
Precipitation (all)										
$\tilde{n}_1$	0.600	0.002	0.423	0.132	0.585	0.000	0.439	0.089	0.405	0.000
$\tilde{n}_2$	0.415	0.000	0.304	0.075	0.306	0.085	0.317	0.053	0.157	0.255
$\tilde{n}_3$	0.196	0.072	0.105	0.675	0.204	0.058	0.246	0.009	0.100	0.505
$\tilde{n}_4$	0.064	0.189	0.037	0.469	0.037	0.475	0.020	0.708	0.019	0.740
Precipitation (homogeneous Group 1)										
$\tilde{n}_1$	0.581	0.000	0.379	0.080	0.566	0.000	0.363	0.110	0.376	0.000
Precipitation (homogeneous Group 2)										
$\tilde{n}_1$	0.574	0.000	0.271	0.464	0.554	0.000	0.257	0.587	0.345	0.000
$\tilde{n}_2$	0.198	0.144	0.217	0.072	0.171	0.229	0.155	0.367	0.066	0.709
Precipitation (homogeneous Group 3)										
$\tilde{n}_1$	0.568	0.000	0.470	0.001	0.489	0.040	0.354	0.130	0.380	0.000
Monthly discharge										
$\tilde{n}_1$	0.732	0.000	0.599	0.000	0.645	0.000	0.624	0.000	0.634	0.000
$\tilde{n}_2$	0.250	0.026	0.387	0.000	0.216	0.104	0.252	0.015	0.152	0.005
$\tilde{n}_3$	0.207	0.000	0.167	0.018	0.174	0.012	0.172	0.015	0.121	0.048
$\tilde{n}_4$	0.057	0.122	0.013	0.703	0.070	0.081	0.061	0.090	0.038	0.356

At monthly, multiannual and seasonal level, the association of ENSO with the discharges ($\tilde{n}_1$=0.634) is greater than with the precipitation ($\tilde{n}_1$=0.405), this result is confirmed by the analyses with the 3 homogeneous groups of precipitation ($\tilde{n}_1$=0.376, $\tilde{n}_1$= 0.345 and $\tilde{n}_1$= 0.380). The major association with the discharges is possibly caused by the effect of ENSO on the soil moisture and the evapotranspiration; the reduction of the soil moisture during the warm phase of ENSO (El Niño) imposes conditions of water stress, and therefore, a reduction in the evapotranspiration process of plants coverage at the basins. Likewise, the extreme hydrological events, have a positive feedback on themselves: drought conditions due to a mesoscale forcing produce decreasing of the rainfall, and therefore, decreasing of the soil moisture, that in turn, reduces the evapotranspiration, causing a less moisture availability for the atmospheric convection, which would produce convective rainfalls. The above mentioned factors are also valid for very rainy periods (La Niña), (Mesa et al, 1997).

The higher seasonal association of ENSO with the monthly precipitation occurs in the periods: DJF ($\tilde{n}_1$=0.600) and JJA ($\tilde{n}_1$=0.585); while in SON ($\tilde{n}_1$=0.439) and MAM ($\tilde{n}_1$=0.423) this decreases. The previous results are confirmed by the analyses for the homogeneous precipitation groups. Likewise, the seasonal association of ENSO with the discharges is higher in DJF ($\tilde{n}_1$=0.732) and JJA ($\tilde{n}_1$=0.645), being small in MAM ($\tilde{n}_1$=0.599) and SON ($\tilde{n}_1$=0.624). These previous factors indicate that in DJF and JJA the ENSO has a higher effect on the regional hydrometeorology, while in MAM and SON its impact is minor.

3.2 Canonical correlation analysis as predictive tool. Supposing that Z**t** is a series of multivariate time and defining: $X_t = Z_t$ and $Y_t = Z_t + \hat{o}$ for a positive lag time τ, the application of the ACC algorithm, truncating previously variables, identifies patterns tending to appear together, with a lag-time for the same variable. Thus, the obtained patterns, describe the best lineally auto-predictable components. Applying this method, the results obtained with the canonical correlation analyses between the macroclimatic variables principal components, precipitation and discharge groups are presented. These patterns are also known with the name of principal prediction patterns (PPP), (Von Storch and Zweirs, 1999).

The application of PPP for lag-time 1 for the prediction of the precipitation allowed to do a more robust and reliable estimation for the parameters of the models; the inclusion of the first 5 PC of the macroclimatic variables in the predictable variables improved the adjustment and decreased the mean quadratic error 3.40%, 2.99% and 4.95% in average, for the stations of the homogeneous groups 1, 2, and 3 respectively; while for the discharges the quadratic mean error decreased 7%, in average, and the adjustment improved 8.4% in average.

The variables with major weight and association in the first canonical pattern are: ocean temperature in the region Niño 4, wind speed in the west Pacific ocean, long wave radiation and the south oscillation index. The difference or equality of signs among each pattern's coefficients, indicate the inverse or direct relationship that exists between the macroclimatic variables and the precipitation. The patterns obtained among the group of macroclimatic variables, the different homogeneous precipitation groups, and the discharge, verified the robustness of the analysis by reporting similar results. The temperature coefficients on the ocean Pacific have contrary sign to the precipitation ones, indicating that an increment of the temperature in the Pacific is associated with a decreasing of the precipitation in the study area. The physical explanation of the process, is related with the alteration of the temperature gradient in the Pacific between the costs of Colombia and Peru, influencing the hydrometeorology of the area, perturbing the advection of the cold and humid air of the Pacific ocean toward the Colombian side.   During the warm phase of ENSO (El Niño) occurs a displacement of the convection centre of the convergence intertropical area (ZCIT) toward the Southwest of its normal position (Pulwarty and Diaz, 1993), with the consequent reduction of the precipitation and the discharges in the warm phase of ENSO (El Niño), and the increment during the cold phase (La Niña).

The wind speed in the west Pacific is directly related with the occurrence of precipitation in the region, since on the Pacific coast superficial winds coming from the west contributes to the moisture advection coming from the ocean Pacific toward the inside of the country. During the cold phase of ENSO (The Niña), these winds are intensified and interact with the predominant ALISIOS winds coming from east, causing high atmospheric instability, strong and deep convection, and high precipitation on the Colombian Pacific coast. During the warm phase (El Niño), these winds are weaken and the advection of wet air decreases, with the consequent decreasing of precipitation, (Velasco and Frisch, 1987).

The south oscillation index is directly related with the hydrometeorology; when it becomes more negative, the precipitation and the discharge in the region decrease, and vice versa. Can be said, that the south oscillation is the atmospheric part of the phenomenon ENSO and it represents, from a conceptual point of view, the change from high to low pressures which is given in the poles of the Walker´ s cell during the ENSO events. This change is measured by means of the SOI index, which is the anomaly of the difference of monthly mean pressure between Tahiti (French Polynesia) and Darwin (Australia). The physical explanation on the decreasing of the precipitation during The El Niño (low SOI values and high temperatures in the Pacific ocean) is given by the establishment of an anomalous Hadley ´s cell on the north of South America (Rasmusson and Mo, 1993) whose descending component prevents the convective rise on the region and it contributes to the decrease of the precipitation. Aceituno (1988) and

Hastenrath and Greischar (1993) indicate that the climatic anomalies on the region are associated to a displacement toward the Equator of the high pressure area of the north Atlantic, which explains, to some extent, the displacement of the convection centre of the convergence intertropical area of ZCIT toward the Southwest of its normal position (Pulwarty and Diaz, 1993), with the consequent decreasing of the precipitation and the discharges during the warm phase of ENSO (El Niño), and the increments during the Cold phase (The Niña).

4 Conclusions

The influence of the ENSO´s variability on the hydrometeorology of Valle del Cauca State, Colombia was investigated finding that a very important teleconnections exists between the big atmospheric circulation systems and the region. ENSO presents a major effect on the discharges than on the precipitations. It is concluded that for the quarterly MAM and SON, it has a minor impact and association with the regional hydrometeorology, while DEF and JJA, are the periods with higher impact and association.

The results provide reliability for the application of FOES and ACC in order to understand ENSO and similar phenomena under local or regional perspectives. The results coincided with previous observations and other statistical analyses at great scale. In Valle del Cauca State, Colombia the warm phase of ENSO (El Niño) is associated to the decrease of precipitation and discharges, while the cold phase (La Niña) is associated to an increase of the same variables.

The application of the principal prediction patterns for the precipitation and the discharges allowed to do a more robust estimation for the parameters of the models. The inclusion of first 5 PC of macroclimatic variables in the group of predictor variables, improved the fit and decreased the mean quadratic error for the predictions in 3.40%, 2.99% and 4.95% in average, for the homogeneous groups 1, 2, and 3 respectively. For the discharge, the fit improved, and the mean quadratic error decreased 7% in average, indicating that the macroclimatic variables supply information for the prediction. The discharge models presented good fit, for what they can be used for prediction.

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