JP1.10 ENSO EVENTS, RAINFALL VARIABILITY AND THE POTENTIAL OF SOI FOR THE SEASONAL PRECIPITATION PREDICTIONS IN THE SOUTH OF CORDOBA-ARGENTINA

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1. INTRODUCTION

Weather conditions and soil moisture along the coming crop season are common and persistent questions of the farmer throughout the year. Uncertainties about the future weather promote a high demand of weather information at the time close to planting, to define the best cultural practices and sustainable combinations for their agricultural production systems (Rivarola et al., 2002) Climate change and climate variability are more evident every day through the changing in the weather variables and also in the responses of the biological systems. The inter-annual variability of the precipitations poses the main restriction to any farm size or farming system and increases the risk associated to the agricultural decisions.

In the agricultural areas of Argentina and particularly in the south of the province of Cordoba, climate variability has become a very significant feature of the farming system. During the cropping season of the summer crops (September-March), corn, soybean, and peanut are the main options in this region. These crops are sensitive not only to the availability of water at planting but also during crop development (December to February), when the water demand is normally the highest of the season (Seiler et al., 1995).

El Niño is one part of a multi-year cycle of the coupled ocean-atmosphere interaction in the tropical Pacific, called El Niño-Southern Oscillation (ENSO) (WMO, 1995) and it has been recognized as one of the controls of the precipitation variability. The ENSO phenomenon involves two extremes phases: a warmer (El Niño) and cold (La Niña) ocean events, that affect atmospheric circulation, disturbing normal pattern of air pressure, tropical rainfall, and winds, leading to changes in the weather around the globe (Ropelewski and Halpert, 1989; NOAA, 1997). Years that do not fall in these extreme phases are referred as Neutral. In the main agricultural area of Argentina warm ENSO events were associated with enhanced likelihood of higher than the median precipitation anomalies during October-February, while lower than the normal precipitation during the same period was typical of cold ENSO events (Messina, et al. 1999; Ropelewski and Halpert, 1989). Seiler and Kogan (2002) working with NOAA-AVHRR indices found significant responses of crops and vegetation to El Niño and La Niña years. Although strong ENSO related precipitation signal over central-eastern Argentina was found for November-January precipitation (Ropelewski and Halpert, 1989; Podesta et al., 1999), Ropelewski and Halpert, (1996) and Tanco and Berri (1996) found the association between rainfall anomalies and the cold phase stronger than for warm events in the region. In the west of that region and particularly in the south of Cordoba little is known about the magnitude of the ENSO signal where precipitation occurrences may be also affected by local factors and processes. This study attempts to quantify the regional signal of the ENSO phases in the rainfall anomalies and its potential for the application in seasonal climate forecasts in agriculture.

2. MATERIAL AND METHODS

The present study is based on series of 40 years of rainfall data collected at seventeen locations within the southern region of the province of Cordoba, Argentina. The analysis of four locations out of the seventeen is presented in this work. Two of them are in the east of the region, Isla Verde (33°15’ S, 62°25 ’W) and Marcos Juarez (32°41’S, 62°07’ W), and two in the west, Rio Cuarto (33º 07′ S, 64°14’ W) and Laboulaye (34º 08′ S, 63°22’ W) (Figure 1). Monthly precipitation data sets were available from the National Weather Service’s weather station in Laboulaye, from the agrometeorological station at the University of Rio Cuarto (UNRC), and from the National Institute for Agricultural Technology (INTA) in Marcos Juarez. Records from Isla Verde were obtained from a farmer cooperative station of the UNRC cooperative observation network. The record length for all the stations was from January 1961 through December 2000.

Derived precipitation variables were generated by the accumulation of the monthly precipitation values over different calendar periods, i.e. from July of one year to June of the next year (**Jul-Jun**), and for shorter periods which may be associated to sensitive stages of the crops cycles. Other considered periods and derived variables were: October to December (**Oct-Dec**), October to March (**Oct-Mar**), November to

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December (**Nov-Dec**), December to January (**Dec-Jan**), January to February (**Jan-Feb**), January to March (**Jan-Mar**) and November to January (**Nov-Jan**). For each precipitation series, these variables were calculated as the sum of millimeters for each period and as deviations from the mean of the period.

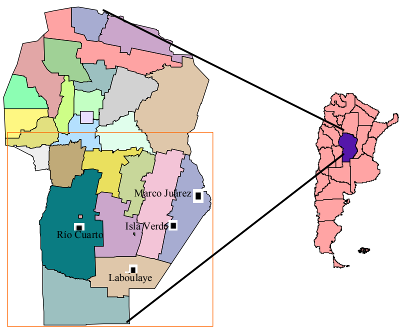

Figure 1: Study area

The phase and strength of ENSO events are defined by indices. One of them is the Southern Oscillation Index (SOI) (Troup, 1965), which is based on the standardized difference of the pressure between Tahiti and Darwin. Other indices commonly used to classified ENSO events include the sea surface temperature (SST) in the called Niño-1+2, Niño-3, etc. Although there is no consensus as to which is the best, Hanley et al., (2003) found in their analysis that SOI, Niño-3.4 and Niño-4 are almost equally sensitive to El Niño events and are more sensitive than the JMA (Japan Meteorological Agency), Niño-1+2 and Niño-3 indices. Besides that, SOI has shown significant correlation with the following monthly precipitation and hence it is an important variable for seasonal climatic forecast and for crop production estimates (Meinke et al., 1996; Hammer et al. 1996; Meinke and Hammer, 1997). For this analysis monthly records of SOI were available for the same precipitation record (http://www.longpaddock.qld.gov.au/SeasonalClimateoutlook/SouthernOscillation Index/SOIDataFilesindex. html).

Correlation analysis (Pearson) between the monthly SOI values and monthly and derived precipitation variables was applied to each location. Correlation coefficients and significance level were analyzed considering the SOI monthly value of one month and the accumulated precipitation of different months later in the same year and in the next, trying to identify a signal that determines the amount of the incoming rainfall (i.e. SOI of March and accumulated rainfall of **Oct-Dec** or **Oct-Mar**). Years in the series were classified as Niño, Niña and according to the JMA index (JMA, 1991) (Table 1), and the mean precipitation of the derived variables for Niño and Niña years was compared to the mean of Neutral years. A t-test was used to test the hypothesis of equal means and an F-test for equality of variances (Snedecor and Cochram, 1980).

Table 1. ENSO events for the period 1961 – 2000. Years not listed are considered to be Neutral.

ENSO	Years								
Niño	1963/64	1965/66	1969/70	1972/73	1976/77	1982/83	1986/87	1987/88	1991/92
	1997/98								
Niña	1964/65	1967/68	1970/71	1971/72	1973/74	1975/76	1988/89		

3. RESULTS AND DISCUSSION

3.1 *SOI-precipitation relationships*

Monthly SOI and precipitation relationships are shown for each of the analyzed locations and variables (Figures 2, 3, 4 and 5). From the whole correlations matrix only those variables with significant correlation values are displayed in those figures. All the correlations in the figures are negative *r* values, but displayed as positive by convention. In Laboulaye, the value of the correlation coefficients increases towards the end of the year as the derived precipitation variables are more related to the SOI of the last months of the year (Figure 2). **Nov-Jan**, **Oct-Dec** and **Dec-Jan** precipitation periods were the precipitation variables that showed better correlations with the monthly SOI. They start to reveal higher correlations with the SOI of June and continue to the SOI of October. The highest correlation for Laboulaye (r = 0.64) is observed between **Nov-Jan** precipitation and the SOI of October. In Rio Cuarto (Figure 3), SOI of March and September show significant correlation with **Nov-Dec** precipitation and **Nov-Jan** precipitation, even though the correlation coefficients were lower than in Laboulaye (e. g. r = 0.44 and r = 0.46 for March and September SOI, respectively).

Similar situation to Rio Cuarto is observed in Isla Verde, in the east of Cordoba (Figure 4). SOI of March and October correlate with **Nov-Dec**, **Nov-Jan** and also with **Oct-Dec** precipitation values. The highest r values for the location were 0.43 and 0.41 in March and October, respectively. Marcos Juarez, also in the east of the studied region, shows closer relationships between August and September SOI with **Nov-Dec**, **Oct-Dec** and **Oct-Mar** precipitation periods. The highest correlation values for each month are 0.47 and 0.48, respectively (Figure 5).

In summary, the four locations show similar correlation patterns between SOI and precipitation. There is a general trend to high correlation values between the SOI of March and afterwards between the SOI of August, September or October with the defined precipitation variables, depending on the location. Laboulaye shares the same pattern but also evidence correlations for June and July SOI. Both SOI correlation groups are significant in Isla Verde and Rio Cuarto, while in the other two locations significant relationships are only demonstrated for the SOI group of August, September or October. Analyzing the derived precipitation variables, the periods of **Nov-Dec** or **Nov-Jan** were the ones most related to SOI, in three locations. Those locations situated in the east of the region, show also correlations between the **Oct-Dec** and **Oct-Mar** precipitation with monthly SOI values.

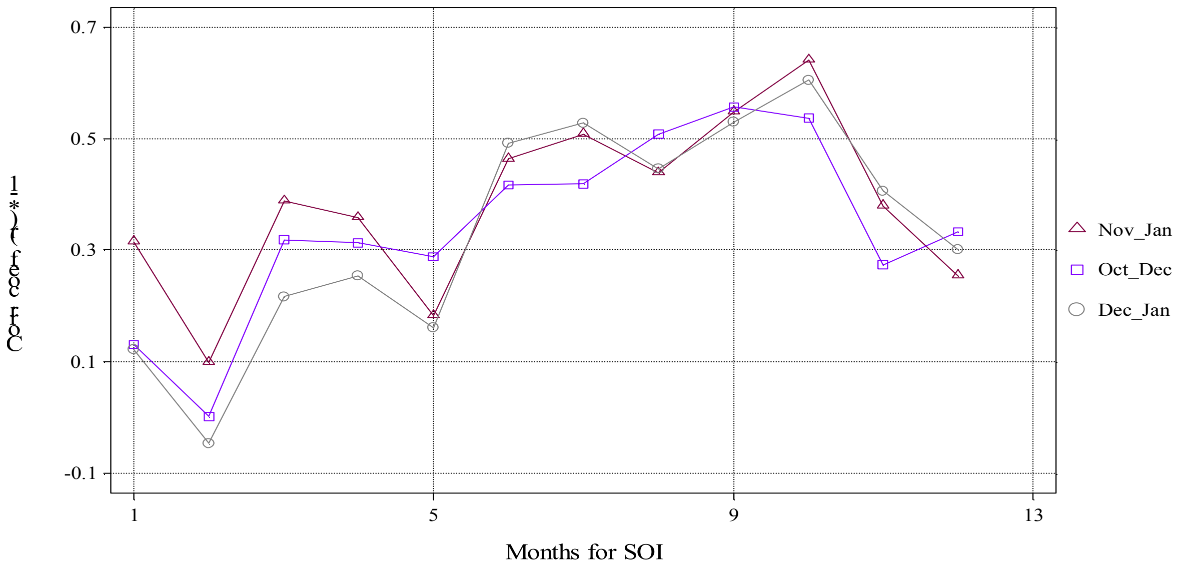

Figure 2. Correlation coefficients between **Nov-Jan**, **Oct-Dec** and **Dec-Jan** precipitation periods, as deviation from the mean of each period, and SOI monthly values in Laboulaye ($r \geq 0.38$ are significant at $p \leq 0.01$).

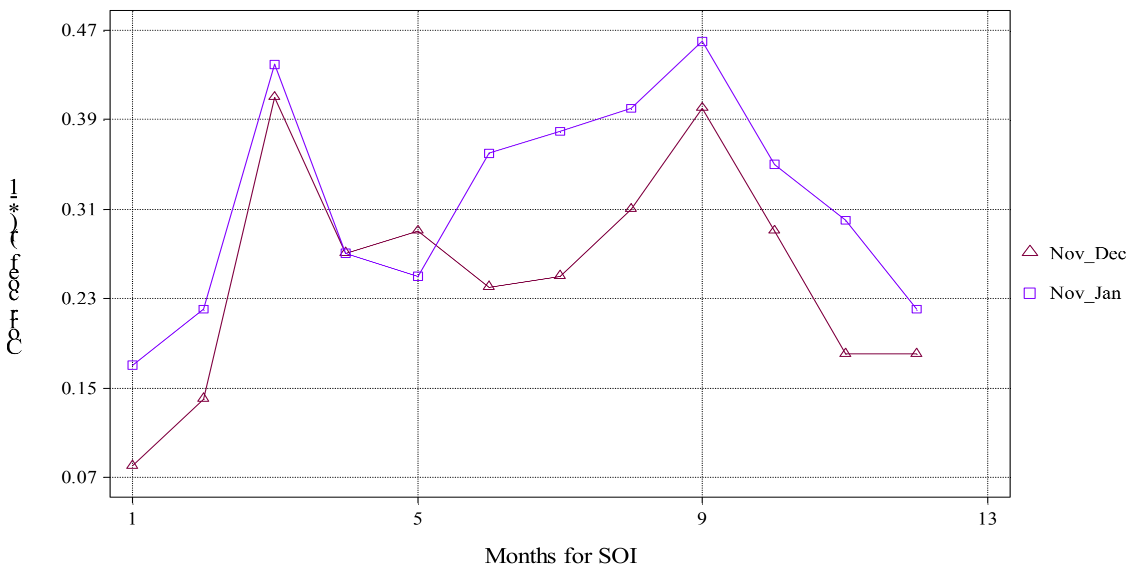

Figure 3. Correlation coefficients between **Nov-Dec** and **Nov-Jan** precipitation periods, as deviation from the mean of each period, and SOI monthly values in Rio Cuarto ($r \geq 0.38$ are significant at $p \leq 0.01$).

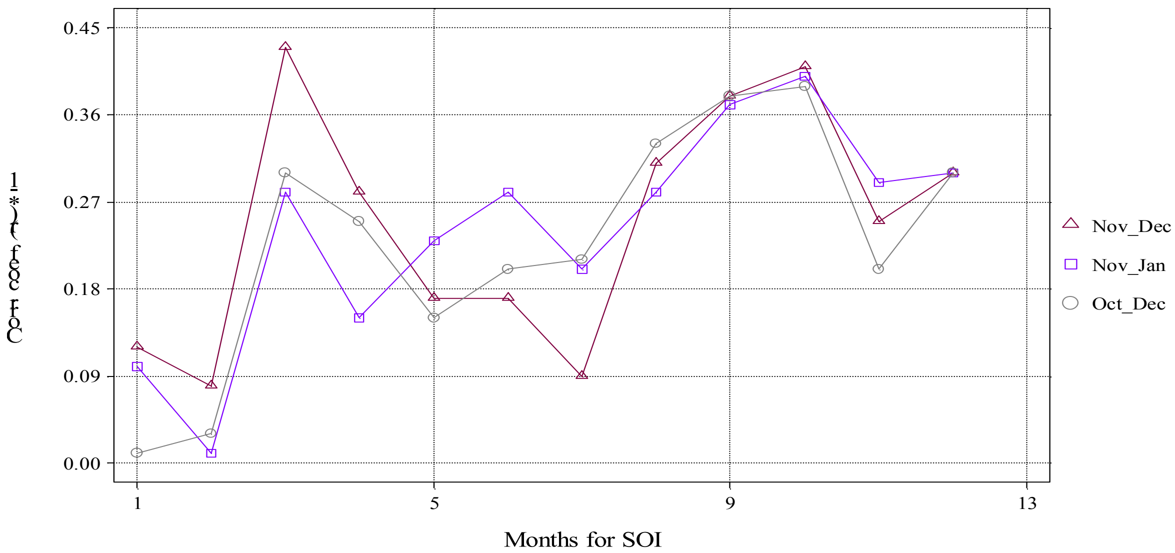

Figure 4. Correlation coefficients between **Nov-Dec**, **Nov-Jan** and **Oct-Dec** precipitation periods, as deviation from the mean of each period, and SOI monthly values in Isla Verde ($r \geq 0.38$ are significant at $p \leq 0.01$).

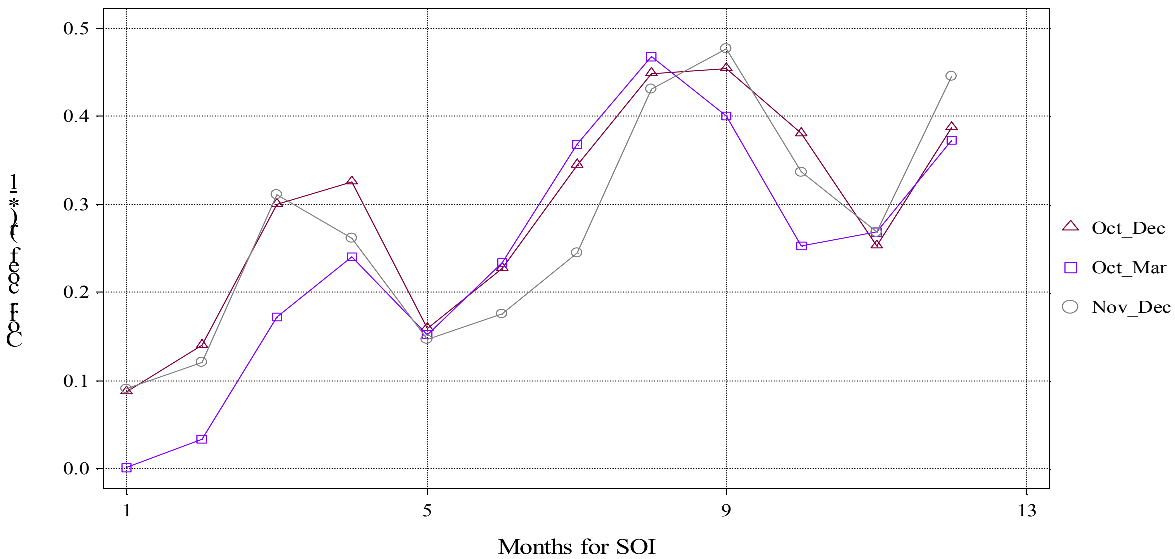

Figure 5. Correlation coefficients between **Oct-Dec**, **Oct-Mar** and **Nov-Dec** precipitation periods, as deviation from the mean of each period, and SOI monthly values in Marcos Juarez ($r \geq 0.38$ are significant at $p \leq 0.01$).

3.2 *The local ENSO signal*

Local effects of the ENSO events in the region were analysed through the differences in the mean of the derived rainfall variables, for the Niño, Niña and Neutral years (Table 1). Mean precipitation of Niño and Niña events were respectively compared with the mean of years, and these differences tested for significance (Tables 2 and 3).

Mean precipitation for each of the derived precipitation variables during El Niño years was rather similar at the four locations. The same characteristic was observed in the region for the Neutral years and also the respective values were comparable in magnitude to those during Niño events. A different situation was observed for La Niña years where consistent lower values of precipitation than that of Neutral years were found for the locations and the variables involved in this analysis. A second characteristic associated to the precipitation of La Niña years is that the differences are higher in the west and south of the region, represented by Rio

Cuarto and Laboulaye (Table 2), than in the east in Isla Verde and Marcos Juarez (Table 3).

Lower La Niña precipitation values than in Neutral years in Rio Cuarto were significant for all the analysed periods at the $p \leq 0.05$. **Jul-Jun**, **Oct-Mar**, **Nov-Dec**, **Dec-Jan** and **Nov-Jan** precipitation differences were significant also at the 1% level. Laboulaye showed the same significant precipitation periods that Rio Cuarto at the 1% level, while in the east the only significant difference ($p \leq 0.01$) was for lower precipitation during the period **Nov-Dec** during La Niña years for both locations (Table 3).

Mean interannual rainfall variability during El Niño years was significative different ($p \leq 0.10$) of the Neutral years, in Rio Cuarto for most of the rainfall periods, except for **Jul-Jun**, **Oct-Dec** and **Oct-Mar**. In Laboulaye and Isla Verde, the non significant periods were **Oct-Dec** and **Nov-Dec** respectively. Variability during La Niña was not different of the Neutral for most of the rainfall periods at all of the locations.

Table 2. ENSO events and seasonal rainfall for the west and south-west locations (Numbers in bold in the T-test column are significant at $p \leq 0.01$ and in the F-test column at $p \leq 0.10$)

Precip/ENSO Phase	*Río Cuarto*				*Laboulaye*			
	Mean	*Anom.*	*T-test*	*F-test*	*Mean*	*Anom.*	*T-test*	*F-test*
Jul-Jun								
Nino	846.5	7.6	0.912	0.383	893.9	33.2	0.603	0.424
Nina	633.1	-205.8	**0.009**	0.239	713.1	-147.5	**0.009**	0.112
Neutral	838.9				860.7			
Oct-Dec								
Nino	351.6	-2.4	0.947	0.144	349.0	39.7	0.306	**0.04**
Nina	246.1	-107.8	0.058	0.549	208.7	-100.6	**0.008**	0.438
Neutral	353.9				309.3			
Oct-Mar								
Nino	682.5	0.43	0.899	0.112	714.8	63.0	0.206	0.51
Nina	492.5	-183.6	**0.005**	0.169	513.9	-137.9	**0.009**	0.243
Neutral	676.0				651.8			
Nov-Dec								
Nino	281.1	10.4	0.732	**0.036**	264.1	32.6	0.275	0.196
Nina	171.0	-99.8	**0.018**	0.186	124.9	-106.6	**0.000**	0.242
Neutral	270.8				231.5			
Dec-Jan								
Nino	281.0	6.9	0.812	**0.061**	257.9	32.1	0.36	0.181
Nina	170.0	-104.1	**0.012**	0.236	152.7	-73.1	**0.001**	**0.037**
Neutral	274.1				225.8			
Jan-Feb								
Nino	218.9	2.6	0.917	**0.015**	193.4	-12.8	0.665	0.164
Nina	156.2	-60.1	0.048	**0.07**	205.6	-0.6	0.987	0.463
Neutral	216.3				206.2			
Jan-Mar								
Nino	330.9	8.8	0.747	**0.013**	365.8	24.5	0.526	0.253
Nina	246.3	-75.8	0.024	**0.065**	305.1	-36.2	0.435	0.375
Neutral	322.1				341.3			
Nov-Jan								
Nino	421.0	17.7	0.645	**0.089**	372.0	29.8	0.462	0.139
Nina	245.6	-157.7	**0.003**	0.184	213.3	-128.9	**0.000**	0.142
Neutral	403.3				342.2			

Table 3. ENSO events and seasonal rainfall for the east locations (Numbers in bold in the T-test column are significant at p≤0.01 and in the F-test column at p≤0.10)

Precip/ENSO Phase	*Marcos Juárez*				*Isla Verde*			
	Mean	*Anom.*	*T-test*	*F-test*	*Mean*	*Anom.*	*T-test*	*F-test*
Jul-Jun								
Nino	943.0	42.0	0.627	0.515	931,4	53.5	0.59	0.232
Nina	801.4	-99.6	0.261	0.329	773.3	-104.5	0.253	0.443
Neutral	900.1				877.9			
Oct-Dec								
Nino	353.8	5.6	0.893	0.439	326.5	-5.8	0.915	0.141
Nina	276.7	-71.6	0.142	0.439	239.7	-92.6	0.105	0.343
Neutral	348.2				323.3			
Oct-Mar								
Nino	717.5	60.2	0.408	0.435	739.3	73	0.273	0.330
Nina	560.9	-96.4	0.222	0.454	549.2	-117.1	0.156	0.283
Neutral	657.3				666.3			
Nov-Dec								
Nino	273.1	24.8	0.507	0.188	259.3	13.5	0.779	**0.078**
Nina	161.3	-87	**0.019**	0.402	132.3	-113.5	**0.003**	0.245
Neutral	248.3				245.8			
Dec-Jan								
Nino	278.2	37.16	0.358	0.458	299.1	54.1	0.238	0.443
Nina	207.9	-33.1	0.467	0.464	206.0	-39.0	0.411	0.467
Neutral	241.03				245.0			
Jan-Feb								
Nino	237.8	13.6	0.753	0.193	261.3	34.9	0.396	0.414
Nina	203.2	-21.0	0.713	**0.102**	227.3	0.9	0.968	0.073
Neutral	224.2				226.4			
Jan-Mar								
Nino	363.7	42.3	0.37	0.452	412.8	67.6	0.161	0.42
Nina	284.3	-37.1	0.549	0.31	309.5	-35.7	0.585	0.267
Neutral	321.4				345.2			
Nov-Jan								
Nino	398.3	51.5	0.263	0.42	405.1	38.1	0.469	0.405
Nina	287.6	-59.3	0.264	0.458	260.8	-106.2	0.059	0.396
Neutral	346.9				367.0			

4. CONCLUSIONS

This regional analysis based on four locations reveals that there is not enough evidence of a clear El Niño signal associated to positive rainfall enhancement during El Niño years, as compared to Neutral years. These results differ from the findings for central-eastern Argentina (Ropelewski and Halpert,1987, 1989; Podesta et al., 1999), where a strong ENSO-related precipitation signal was found during Nov-Jan. Indeed, as stated by Kane (1999) for other regions in South America, local effects and/or different mechanisms appear to be interfering. However, evidence exists of strong La Niña signal, causing significative diminutions of rainfall associated with most of the analysed rainfall periods in the west of the region, and with **Nov-Dec** rainfall period in the east of the region. Rainfall variability during El Niño events compared to Neutral years was higher in the west, but mostly in Rio Cuarto. Differences in the interannual variability of rainfall during La Niña events compared to Neutral years were found for **Jan-Feb** period in Marcos Juarez, Isla Verde and Rio Cuarto. This location also showed differences in the **Jan-Mar** period, and Laboulaye in **Dec-Jan**.

Significant correlation of SOI with rainfall allows the monthly SOI values to be proposed in the region as a basis for seasonal rainfall predictions. Undoubtedly, future research must be done in the same region to identify other predicting variables besides SOI, that may help to improve forecasts. Best correlations were shown between early spring SOI and late spring and summer rainfall periods. For some of the sites in the region, even early as Autumn SOI showed significant correlation with **Nov-Dec** and **Nov-Jan** rainfall. For the highest relationships, 41% of the rainfall variability was captured by the SOI value.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Hammer, G. L., D. P. Holzworth and R. Stone, 1996: The value of skill in seasonal climate forecasting to wheat crop management in a region with high climatic variability. *Aust. J. Agric. Res.*, **47**, 717-737.

Hanley, D. E., Bourassa, M. A., O`Brien, J. J., Smith, S. R. and E. R. Spade, 2003: A quantitative evaluation of ENSO indices. *J. of Climate.,* **16 (8),** 1249–1258.

Kane, R.P., 1999: Rainfall extremes in some selected parts of central and south America: ENSO and other relationships re-examined. *Int.J.Climatol.*, **19**, 423-455

JMA, 1991: Climate charts of sea surface temperature of the western North Pacific and the global ocean. Marine Department, JMA.

Meinke, H. and G. L. Hammer, 1997: Forecasting regional crop production using SOI phases: an example for the Australian peanut industry. *Aust. J. Agric. Res.*, **48,** 789-793

Meinke, H., R. C. Stone and G. L. Hammer, 1996. SOI phases and climatic risk to peanut production: A case study for northern Australia. Int. J. Of Climatology, 16: 783-789.

Messina, C.D., J.W. Hansen, and A.J. Hall, 1999: Land allocation conditioned on El Niño – Southern Oscillation phases in the Pampas of Argentina. *Agric. Sys.,* **60**, 197-212

NOAA (Nacional Oceanic and Atmospheric Administration), 1997: Climate conditions associated with the 1997-1998 El Niño: Impact and outlook. Special climate summary 97/3, 13 Nov. Washington, DC.

Podestá, G.P., C.D. Messina, M.O.Grondona, and G.O. Magrin, 1999: Associations between grain crop yields in central-eastern Argentina and El Niño-Southern Oscillations. *J. Appl. Meteorol.*, **38**, 1488-1498.

Rivarola, A., M.G. Vinocur, and R. A. Seiler, 2002: Uso y demanda de información agrometeoro-lógica en el sector agropecuario del centro de Argentina. RADA, in press

Ropelewski, C.F., and M.S. Halpert, 1989: Precipitation patterns associated with the high index phase of the Southern Oscillation. *J.Climate*, **2**, 268-284

Ropelewski, C.F., and M.S. Halpert, 1996: Quantifying Southern Oscillation-precipitation relationships. *J.Climate*, **9**,1043-1059

Seiler, R. A., R. Fabricius, V. Rotondo y M. Vinocur, 1995: Agroclimatología de Río Cuarto-1974/93, Vol. I. Río Cuarto. Ed. UNRC. 68 pp.

Seiler, R. A**.** and F. Kogan, 2002: Monitoring ENSO cycles and their impacts on crops in Argentina from NOAA-AVHRR satellite data. *Adv. in Space Res.,* **30(11),** 2489-2493.

Snedecor, G. W. and W. G. Cochran, 1980: Statistical Methods. 7^{th} ed. The Iowa State University Press. Ames, Iowa.

Tanco, R., and G. Berri, 1996: Acerca del fenómeno El Niño sobre la precipitación en la Pampa húmeda Argentina. 319-320. *Proc.*VII Congreso Argentino y VII Congreso Latinoamericano e Ibérico de Meteorología, 2-6 Sept., 1996, Buenos Aires, Argentina

Troup, A. J., 1965: The southern oscillation. *Quarterly Journal of Royal Met. Soc.*, **91**, 490 – 506.

WMO (World Meteorological Organization), 1995: The global climate system review: Climate system monitoring, June 1991-November 1993. **WMO No. 819-150**.