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PROBABILISTIC RAINFALL ANOMALIAS IN SOUTHERN BRAZIL ASSOCIATED WITH ENSO

Clóvis A. Sansigolo*
Instituto Nacional de Pesquisas Espaciais, São José dos Campos, São Paulo

1. INTRODUCTION

ENSO extreme events (El Niño / La Nina) are associated with climate extremes over many regions of the globe (Ropelewski and Halpert, 1987, 89, 96) and Kiladis and Diaz, 1989). Over Southern Brazil, Grimm et al. (1998) and Diaz et al. (1998) verified, using different methods (composites and and canonical correlations), that El Niño and La Niña events are respectively associated with below and above-normal rainfall in Spring. Composites of climate anomalies observed during past ENSO events provide useful information on the typical ENSO impact (Kiladis and Diaz, 1998), but the relationships between ENSO and the expected climatic anomalies is not straightforward. For the same ENSO SST structure and magnitude, the inherent atmosphere unpredictability would lead to different climatic anomalies for each event (Hoerling et al, 1997). The non-linear interactions with SST anomalies in the other oceans and the existence of inter-events differences will increase the uncertainties on the expected climatic anomalies (Mason and Goddard, 2001). Correlations and regressions are the methods commonly used for composite analyses They describe the intensity and shape of the linear teleconnections between ENSO and climate anomalies. However, in some regions, the ENSO-climate relationships is asymmetric between El Niño and La Niña events, and varies in strength during the year (Ropelewski and Halpert, 1996). In addition, the correlation coefficients are sensible to the assumption of data normality, so, inappropriate to describe the ENSO-rainfall strength signal in areas with highly skewed rainfall distributions. Given the limitations of composite and linear measures of ENSO influences for forecasting future impacts, it is of value to estimate the probabilities of climate anomalies conditional upon the phase of ENSO (Roplewski and Halpert, 1996, Mason and Goddard, 2001). A simple and robust alternative approach is to use contingency tables that provide a measure for identifying the influence of an independent variable (ENSO) on the probability of a predefined climate event occurring (eg. given rainfall tercile).

*Corresponding author address: Clóvis A. Sansigolo, INPE, CPTEC, DMA, São José dos Campos, SP, Brazil
e-mail:sansigol@cptec.inpe.br

The purpose of this study is to analyze the relationships between ENSO extreme events and rainfall in Southern Brazil using contingency tables, aiming at quantifying, in probabilistic terms, the seasonal impact of El Niño and La Niña events on the rainfall anomalies in the region.

2. DATA AND METHODS

Monthly rainfall data from 1949/50 to 1998 for 70 meteorological stations well distributed all over the region, as shown in figure 1, were used. Also, in Fig. 1 is found the 4 monthly rainfall homogeneous groups and their average monthly rainfall distributions (Sansigolo et al., 2004).

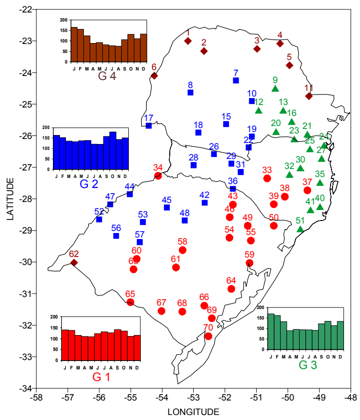

Fig. 1. Geographical distributions of the 70 meteorological stations over Southern Brazil region, the 4 monthly rainfall homogeneous groups, and their average monthly rainfall distributions.

Seasonal (DJF, MAM, JJA, and SON) rainfall average anomalies, from 1949/50 to 98, were sorted and allocated in terciles, corresponding to the categories: below-normal, near-normal, and above-normal. La Niña and El Niño impact were estimated by the number of times that seasonal rainfall were, respectively, in the lower and upper climatological terciles during ENSO extreme events. Seasonal averages of Niño 3.4 index were calculated using Kaplan et al. (1998) SST anomalies. The 11 strongest seasonal El Niño and La Niña events between 1949/50 and 1998, are shown in Table 1 and 2.

Table 1. The 11 strongest seasonal El Niño events between 1949/50 and 1998.

DJF			MAM			JJA			SON		
(σ=1,04^{0}C)			(σ=0,65^{0}C)			(σ=0,68^{0}C)			(σ=0,93^{0}C)		
Year	**SSTA**	$\|\sigma\|_u$	**Year**	**SSTA**	$\|\sigma\|_u$	**Year**	**SSTA**	$\|\sigma\|_u$	**Year**	**SSTA**	$\|\sigma\|_u$
1982/83	*2.62*	*2.52*	*1992*	*1.58*	*2.43*	*1997*	*1.78*	*2.62*	*1997*	*2.47*	*2.66*
1997/98	*2.5*	*2.40*	*1983*	*1.56*	*2.40*	*1987*	*1.62*	*2.38*	*1982*	*1.91*	*2.05*
1957/58	*1.41*	*1.36*	*1987*	*1.26*	*1.94*	*1982*	*1.16*	*1.71*	*1972*	*1.82*	*1.96*
1991/92	*1.8*	*1.73*	*1998*	*1.26*	*1.94*	*1972*	*1.02*	*1.50*	*1987*	*1.67*	*1.80*
1972/73	*1.66*	*1.60*	*1993*	*0.97*	*1.49*	*1965*	*1.00*	*1.47*	*1965*	*1.63*	*1.75*
1965/66	*1.32*	*1.27*	*1958*	*0.79*	*1.22*	*1991*	O.89	*1.31*	*1986*	*1.09*	*1.17*
1986/87	*1.32*	*1.27*	*1966*	*0.63*	*0.97*	*1963*	*0.85*	*1.25*	*1963*	*1.06*	*1.14*
1968/69	*1.06*	*1.02*	*1969*	*0.55*	*0.85*	*1957*	*0.74*	*1.09*	*1991*	*1.03*	*1.11*
1994/95	1.02	0.98	1957	0.52	0.80	1992	0.65	0.96	1994	0.96	1.03
1969/70	0.9	0.87	1991	0.46	0.71	1994	0.51	0.75	1957	0.87	0.94
1963/64	0.84	0.81	1953	0.34	0.52	1958	0.42	0.62	1976	0.86	0.92
avg. 5	2.00	1.92	avg. 5	1.33	2.05	avg. 5	1.32	1.94	avg. 5	1.90	2.04
avg. 8	*1.71*	*1.64*	*avg. 8*	*1.08*	*1.66*	*avg. 8*	*1.13*	*1.66*	*avg. 8*	*1.59*	*1.71*
avg.11	1.50	1.44	avg.11	0.90	1.39	avg.11	0.97	1.43	avg.11	1.40	1.51

***SSTA** are the Niño 3.4 seasonal average SSTA(^{0}C), **σ** the seasonal standard deviation, and **σ_u** average standardized SSTA (SSTA/σ).

Table 2. The 11 strongest seasonal La Nina events between 1949/50 and 1998.

DJF			MAM			JJA			SON		
(σ=1.04^{0}C)			(σ=0.65^{0}C)			(σ=0.68^{0}C)			(σ=0.93^{0}C)		
Year	**SSTA**	$\|\sigma\|_u$	**Year**	**SSTA**	$\|\sigma\|_u$	**Year**	**SSTA**	$\|\sigma\|_u$	**Year**	**SSTA**	$\|\sigma\|_u$
1973/74	*-1.96*	*1.88*	*1974*	*-0.94*	*1.45*	*1988*	*-1.28*	*1.88*	*1973*	*-1.78*	*1.91*
1988/89	*-1.70*	*1.63*	*1971*	*-0.89*	*1.37*	*1973*	*-1.17*	*1.72*	*1988*	*-1.47*	*1.58*
1975/76	*-1.58*	*1.52*	*1989*	*-0.81*	*1.25*	*1975*	*-1.06*	*1.56*	*1975*	*-1.27*	*1.37*
1970/71	*-1.47*	*1.41*	*1975*	*-0.67*	*1.03*	*1970*	*-0.74*	*1.09*	*1955*	*-1.17*	*1.26*
1984/85	*-1.03*	*0.99*	*1985*	*-0.59*	*0.91*	*1964*	*-0.71*	*1.04*	*1970*	*-1.02*	*1.10*
1955/56	*-0.94*	*0.90*	*1956*	*-0.56*	*0.86*	*1956*	*-0.57*	*0.84*	*1964*	*-0.93*	*1.00*
1995/96	*-0.75*	*0.72*	*1955*	*-0.46*	*0.71*	*1974*	*-0.53*	*0.78*	*1971*	*-0.80*	*0.86*
1964/65	*-0.71*	*0.68*	*1968*	*-0.46*	*0.71*	*1971*	*-0.50*	*0.74*	*1998*	*-0.80*	*0.86*
1971/72	-0.59	0.57	1967	-0.42	0.65	1955	-0.48	0.71	1956	-0.66	0.71
1954/55	-0.54	0.52	1964	-0.4	0.62	1954	-0.44	0.65	1974	-0.62	0.67
1962/66	-0.44	0.42	1976	-0.38	0.58	1998	-0.44	0.65	1954	-0.57	0.61
avg. 5	-1.55	1.49	avg. 5	-0.78	1.20	avg. 5	-0.99	1.6	avg. 5	-1.34	1.44
avg. 8	*-1.27*	*1.22*	*avg. 8*	*-0.67*	*1.03*	*avg. 8*	*-0.82*	*1.21*	*avg. 8*	*-1.16*	*1.25*
avg.11	-1.06	1.02	avg.11	-0.60	0.92	avg.11	-0.72	1.06	avg.11	-1.01	1.09

The significance of the number of times that simultaneously and lagged 1 and 3 months observed rainfall anomalies during ENSO extreme events were in each considered tercil was calculated using 3x2 contingency tables (Table 2), where n is the total number of years, a and b the dry and wet years in a random sample r (5, 8 or 11 strongest El Niños x or La Niñas y).

Table 2. Three-by-two contingency table used for verification of a binary system.

	El Nino / La Niña		
Category	*Yes*	*No*	*Total*
Below-normal	y	b-y	b
Near-normal	r-x-y	n-r-b-a+x+y	n-b-a
Above-normal	x	a-x	a
Total	r	n-r	n

The probabilities of x (y) or more wet (dry) years in a random sample r is equivalent to the upper tail area of the hypergeometric distribution (Agresti, 1996):

$$P(X \geq x) = \mathbf{H}(x|r,a,n) = \sum_{k=x}^{\min(r,a)} C_a^k \; C_{n-a}^{r-k} / \; C_n^r \quad (1)$$

In our case, where n=48, a=b=16, and r=8, for example, at least 5 cases should be observed to be significant at 90% probability level, and there is chance of 6.9% to get 5 or more cases.

3. RESULTS AND DISCUSSION

The seasonal rainfall anomalies frequencies in Southern Brazil during the 8 strongest El Niño and La Niña events from 1949/50 to 1998 are, respectively, showed in Figs. 2 and 3.

El Niños impact associated with above-normal rainfall occur during all seasons of the year or all phases of the event, but the greatest ones are in the Southern part of the region in the Austral Spring (developing phase of the event), and in Summer (mature phase of the event). In Autumn (the decreasing phase of the events) there is also a reasonable impact all over the region, despite the decreasing Niño 3.4 SSTA, from 1.71 to 1.08 (Table 1). Although there are significant differences in the seasonal Niño 3.4 anomalies (among ENSO phases) the average standardized anomalies are quite similar.

La Niñas impacts are restricted to a few stations in Spring.

These ENSO impact results are partially in agreement with the ones of Grimm et al. (1998) and Diaz et al. (1998).

Figs. 3 and 4 show the frequencies of 1-month lagged rainfall during the 8 strongest El Niño and La Niña events. El Niños larger impacts are in OND rainfall anomalies, followed by AMJ. The phases of major impacts of El Niño are the same as the simultaneous analyses (developing and mature phases). Also is this case, La Niña impacts are restricted to a few stations in OND (developing phase of the event).

Finally, it is shown in Figs. 6 and 7 the frequencies of 3-months lagged rainfall during the 8 strongest El Niño and La Niña events. The major impacts of El Niños are in Spring rainfall followed by Autumn rainfall, corresponding, respectively, to the initial and mature phases of the events. La Niñas 3-months lagged impacts are restricted to their initial phases (JJA) in Spring rainfall all over the region.

The results were only presented for the 8 strongest ENSO events because they were quite similar when considering the 5 and 11 strongest ones.

Comparing Figs. 2, 4, and 6 with 3, 5, and 7 it can be verified that the impact of El Niño events associated with above-normal rainfall is greater than La Niña events associated with below-normal rainfall. This emphasizes a remarkable asymmetry between both events related to the seasons (phases) of significant impact and extent.

As ENSO events have a significant impact on the rainfall anomalies in the region, it seems reasonable to use relative frequencies such a those shown in Figs 2 – 7 to derive probabilistic estimates of a rainfall anomaly for a season in which an ENSO event is present or forecasted.

4. CONCLUSIONS

El Niño events associated with above normal rainfall anomalies have greater impact than La Niñas associated with above normal rainfall in Southern Brazil region.

The seasons of major impacts of El Niño are, respectively, the Spring (developing phase), and Summer (mature phase). La Niñas have a restricted impact in Spring.

The high ENSO predictability (Latif et al.,1998) and Its great impact over Southern Brazil rainfall provide a significant source of predictability of the seasonal rainfall variability in the region.

5. REFERENCES

Aceituno, P. 1988: On the functioning of the Southern Oscillation in the South American sector. Part I: Surface climate. *Mon. Wea. Rev.* **116**, 505-524.

Agresti, A .1996: *Introduction to Categorical Data Analysis*. John Wiley, 290pp.

Diaz, A; C.D. Studzinski, and C.R. Mechoso, 1998: Relationships between precipitation anomalies in Uruguay and Southern Brazil and sea surface temperature in the Pacific and Atlantic oceans. *J. Climate* **11**, 251-271.

Grimm, A.M; S.E.T. Ferraz, and J. Gomes, 1998: Precipitation anomalies in Southern Brazil associated with El Niño and La Niña events. *J. Climate* **11**, 2863-2880.

Hoerling, M.P.; A Kumar, and M. Zhong, 1997: El Niño, La Niña, and the non- linearity of their teleconections. *J. Climate* **10**, 1769-1786.

Kaplan, A.; M.A. Cane; Y. Kushnir; A. Clement; M. Blumenthal, and R. Rajagopalan, 1998: Analyses of global sea surface temperature 1856-91. *J. Geophys. Res*. **103**, 18567-18589.

Latif, M.D., L.T. Anderson, T.P. Barnett, M.A. Cane, R. Kleeman, A. Leetmaa, J. O'Brien, A. Rosati & E. Schneider. 1998: A review of the predictability and prediction of ENSO. *J. Geophys. Res.* **103**, 14375-14393.

Mason, S. and L. Goddard, 2001: Probabilistic precipitation anomalies associated with ENSO. *Bull. Amer. Met. Soc*. **82**, 619-638.

Ropelewski, C.F., and M.S. Halpert, 1987: Global and regional scale precipitation patterns associated with the El Niño Southern Oscillation. *Mon. Wea. Rev*. **115**, 1606-1626.

Ropelewski, C.F., and M.S. Halpert, 1989: Precipitation patterns associated with the high index phase of the Southern Oscillation. *J. Climate* **2**, 1607-1626.

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

Sansigolo, C.A.; C.S. Pereira, and I.R. Silva. 2004: Relações entre as precipitações regionais no Sul do Brasil e as temperaturas da superfície dos oceanos Atlântico e Pacífico. *Rev. Bras. Met.* **19**, 5-11.

Wilks, D.S. 1995: *Statistical Methods in the Atmospheric Sciences*. Academic Press, 467 pp.

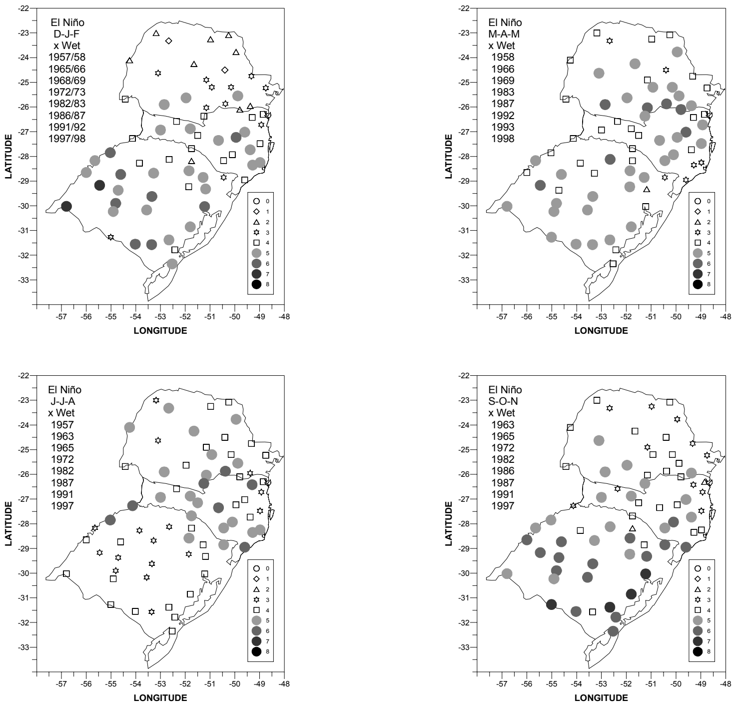

Fig. 2. Frequencies of above-normal seasonal rainfall during the 8 strongest El Niño events from 1949/50 to 1998. Five or more cases (circles) are significant at 90% probability level.

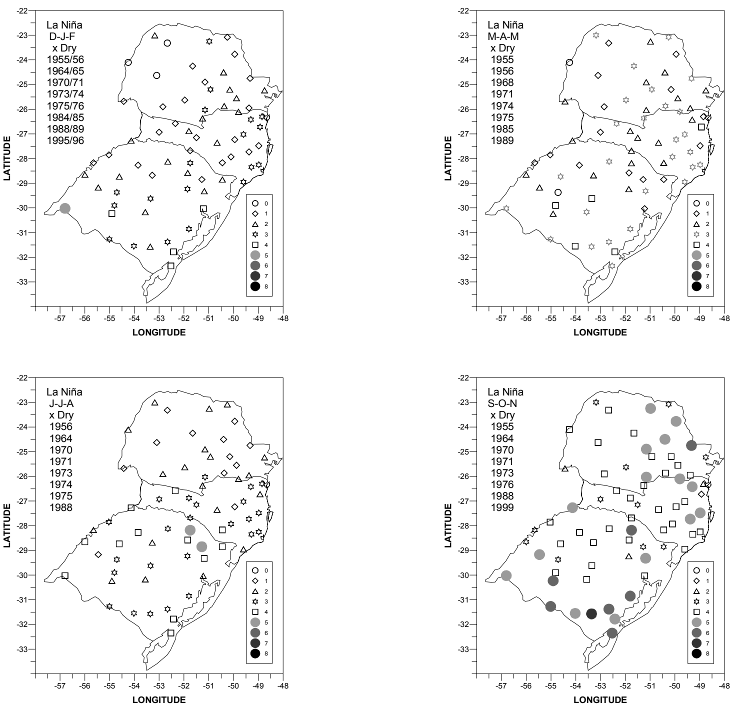

Fig. 3. Frequencies of below-normal seasonal rainfall during the 8 strongest La Niña events from 1949/50 to 1998.

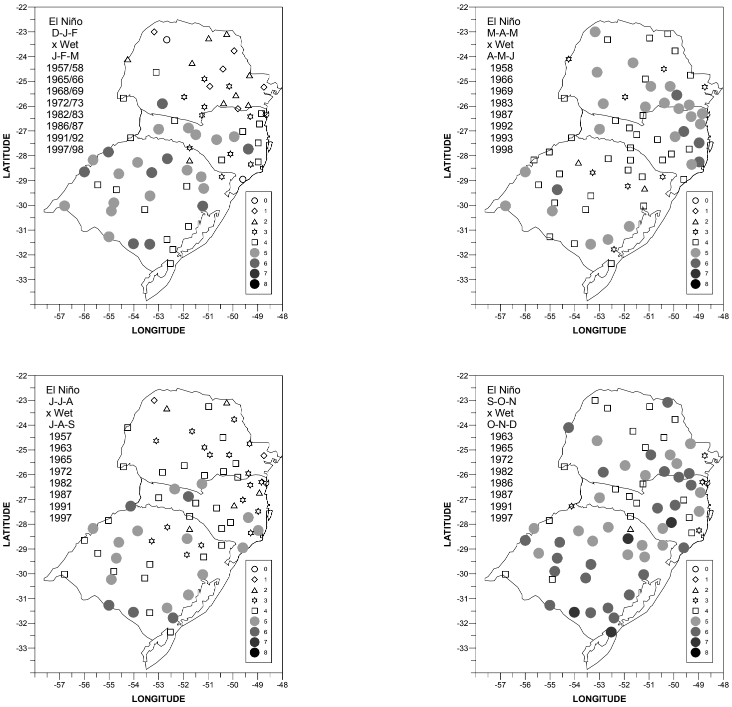

Fig. 4. Frequencies of 1-month lagged above-normal seasonal rainfall during the 8 strongest El Niño events from 1949/50 to 1998.

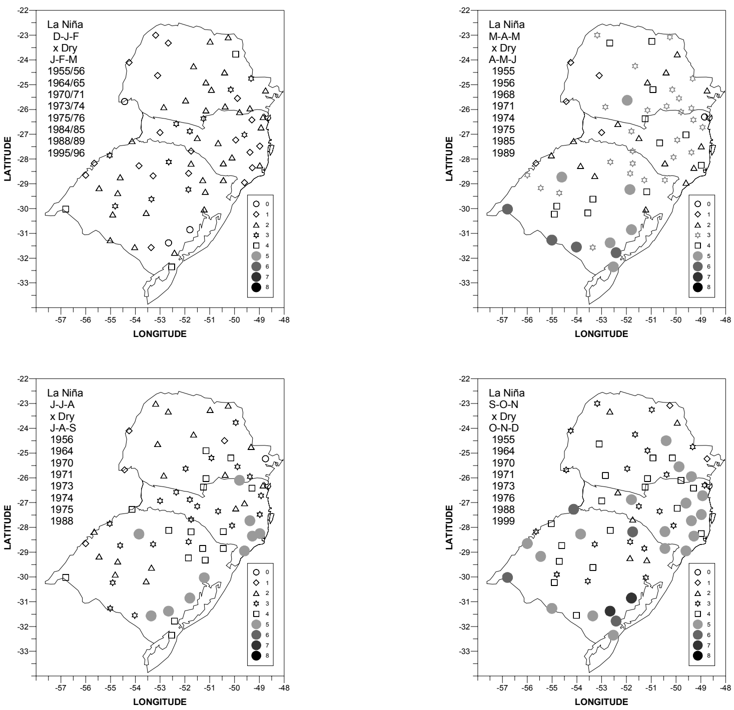

Fig. 5. Frequencies of 1-month lagged below-normal seasonal rainfall during the 8 strongest La Niña events from 1949/50 to 1998.

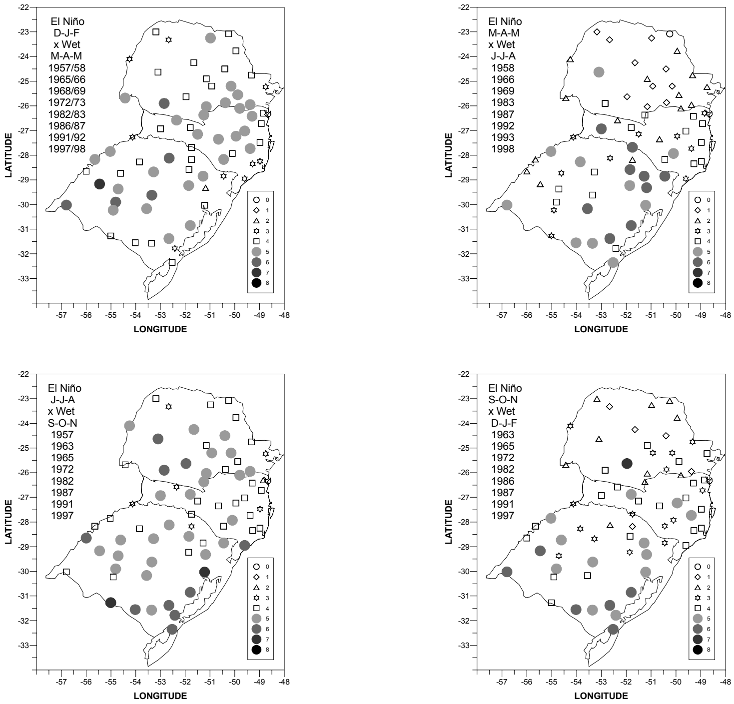

Fig. 6. Frequencies of 3-months lagged above-normal seasonal rainfall during the 8 strongest El Niño events from 1949/50 to 1998.

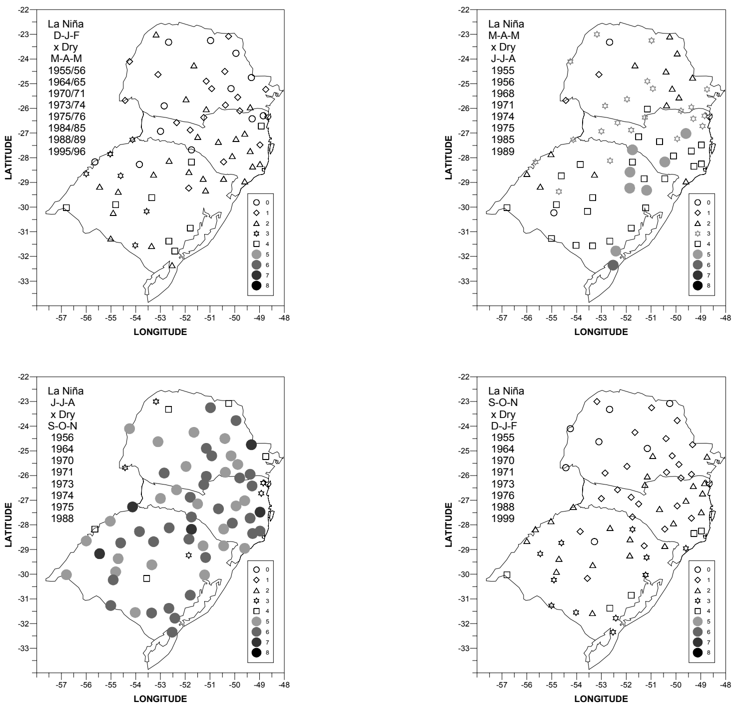

Fig. 7. Frequencies of 3-months lagged below-normal seasonal rainfall during the 8 strongest La Niña events from 1949/50 to 1998.