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CLIMATOLOGY OF 1000 HPA WEATHER TYPE CIRCULATIONS IN SOUTHERN SOUTH AMERICA. ASSOCIATION WITH RAINFALL EPISODES.

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1. INTRODUCTION

Climate variations have significant economic and social consequences, particularly in regions with an important world agricultural production. The study of climate variability in terms of the characterization of the atmospheric circulation and its relation with local climate is a useful tool for climate diagnostics. There are few studies where the objective identification and classification of synoptic patterns in southern South America has been performed. In the opposite, these topics have been intensely discussed in the Northern Hemisphere and other regions of the planet (Mo and Ghil, 1988; Michelangeli et al., 1995; Kidson, 2000, among others). However, as first approximations to objective synoptic classifications in southern South America Compagnucci and Vargas (1985), Compagnucci and Salles (1997) and Compagnucci et al. (1998) identified the principal spatial patterns by means of principal component analysis of observed daily sea-level pressure. Solman and Menéndez (2003) classified winter daily fields of 500 hPa geopotential heights for the period 1966-1999 by means of K-means clustering technique and studied their relationship with precipitation and temperature in Argentina. Bischoff and Vargas (2003) studied the 500 and 1000 hPa weather type circulations and their relationship with some extreme climatic conditions using reanalyses developed by the ECWMF for the period 1980-1988.

The aim of this work is to advance towards the objective identification of weather type circulations (WT) in the South American sector and analyze their main characteristics, frequency, distribution and temporal variability during the period when major precipitations in central-eastern Argentina occur (October to May). An objective classification of daily surface circulation fields is proposed by using a long database in order to relate these weather types to rainfall episodes in the argentine Pampas region.

2. DATA AND METHODOLOGY

Daily anomalies of 1000 hPa geopotential heights for the period 1979-2001 were used in order to perform the weather type (WT) classification. The series of 5346 daily maps was obtained from the NCEP Reanalysis 2 data provided by the NOAA-CIRES Climate Diagnostics Center. The months analyzed were those when major precipitations in central-eastern Argentina occur (October to May). This period also corresponds to the growing season of the summer crops in this area. The domain chosen extends from 60°S to 20°S and from 90°W to 30°W including 475 gridpoints (2.5 x 2.5 latitude-longitude grid).

Principal component analysis (PCA) was performed (Richman, 1986; Jolliffe, 1986) coupled with cluster analysis (CA) (Wilks, 1995) to determine the weather types. PCA combined with CA classifies circulations patterns by performing cluster analysis in the daily loading for each principal component retained. The method of clustering used in this work is a K-means algorithm, which produces exactly K different clusters of greatest possible distinction with the goal to minimize variability within clusters and maximize variability between clusters. As shown by Gong and Richman (1995) this method combined with PCA can provide the most separable system of cluster.

High quality daily station datasets were used in this analysis in order to link the WT with the regional climate. Although there are more raingauges in this region only 5 stations, obtained from the Argentine Meteorological,

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Service were deemed appropriate for the analysis with long records; less than 10% of missing data; and continuity of records. The used stations were: Paraná Aero (31°47'S; 60°29'W), Marcos Juárez Aero (32°42'S; 62°9'W), Rosario Aero (32°55'S; 60°47'W), Junín Aero (34°33'S; 60°55'W) and 9 de Julio (35°27'S; 60°53'W). The analyzed period was coincident with the one of reanalysis. The restrictive criterion used in this work to characterize days as a function of rainfall was based on Bettolli et al. (2005): a) rainy days: days with rainfall exceeding 0.1 mm in all stations b) heavy rainy days: days with rainfall exceeding 10 mm in all stations; c) dry days: days with no rainfall over the whole area.

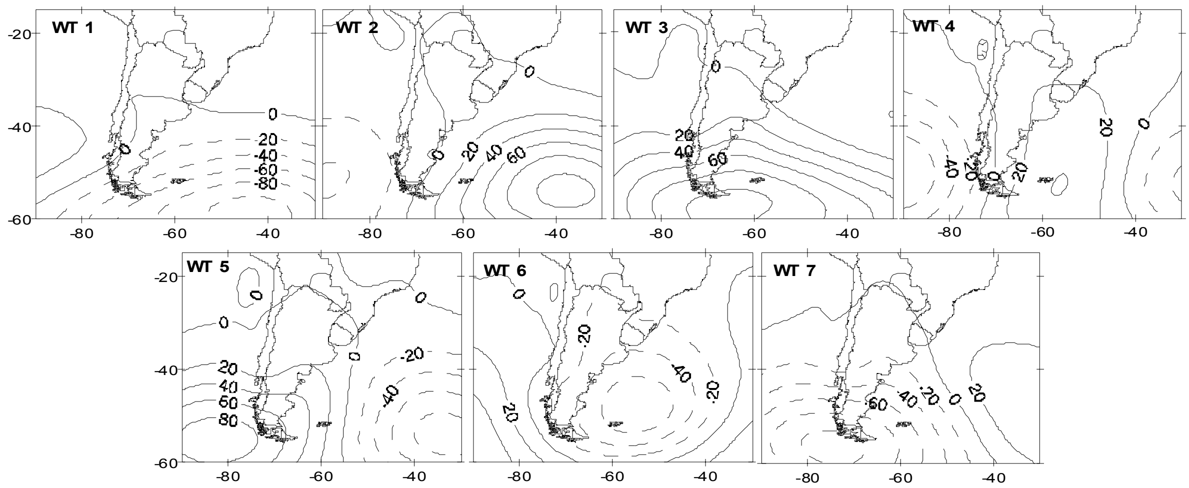

Figure 1. Spatial patterns of 1000 hPa WT

3. RESULTS

3.1 Weather Patterns

Using k-means clustering method on the most relevant T-mode principal components, a classification into 7 fundamental circulations emerged. Separation between the centers of two clusters can be measured by means of the correlation coefficient between them and it should not exceed a threshold taken as 0.36 (Mo y Ghil, 1988). For the 7 clusters found here, the highest correlation value found was 0.38, which is an acceptable threshold for separation considering the big number of pairs involved in the calculation (475 pairs). The WT spatial patterns are presented in Figure 1 and their characteristics are summarised in Table 1. WT2 and WT6 are the less frequent patterns although there is a little variation in group frequencies.

The temporal series of seasonal frequencies of the 7 synoptic patterns were studied in order to find main characteristics, even though the analyzed period in this work is relatively short to infer temporal variabilities (Figure 2). Major interannual variabilities are found for those groups with enhanced westerlies (WT1 and WT7) while the opposite behavior is found for those days characterized by a ridge at the east of the continent (WT4) inducing subsidence at low levels and warm advection.

Table 1. Frequency of occurrence and characteristics of the 1000 hPa WT

WT	*Frequency*	*Description*
WT1	15.4 %	Negative anomalies over the SW Atlantic. SW flow over the continent
WT2	16.4 %	Negative anomalies over the SE Pacific and positive anomalies over the SW Atlantic
WT3	13.9 %	Positive anomalies over the southern tip of the continent
WT4	10.9 %	Positive anomalies over the E of the continent
WT5	15.9 %	Positive anomalies over the SE Pacific and S of the continent and trough downstream
WT6	11.3 %	Negative anomalies centered 45S-55W
WT7	16.2 %	Negative anomalies over the southern tip of the continent

The maximum in the temporal series of this group is found for the period 1994/95, and it is coincident with precipitations below normal during 1994 and the following drought in 1995 that affected a vast region of Argentina (Alessandro y Lichtenstein, 1996). It is observed a progressive diminution in time of cold air advection situations (WT5) (significant linear trend at 5%) associated with an anticyclone which induces stability conditions at low levels. This result is coincident with the increase of summer minimum temperature values observed in recent decades over the studied area (Easterling et al., 1997; Rusticucci and Barrucand, 2004) which depend mainly on the night-time radiative effect. Meanwhile an increase in seasonal frequencies of enhanced mid-latitude westerlies and disturbances migration over Patagonia (WT7) is detected. This result is in agreement with the gradual increase in annual precipitation observed in recent decades over this area (Hoffmann et al. 1987; Castañeda and Barros 1994; Penalba and Vargas 1996). This group exhibits pronounced low frequencies in the strongest El Niño years (1982/83, 1991/92 and 1997/98) showing changes at low level circulation and in westerlies intensity during these years.

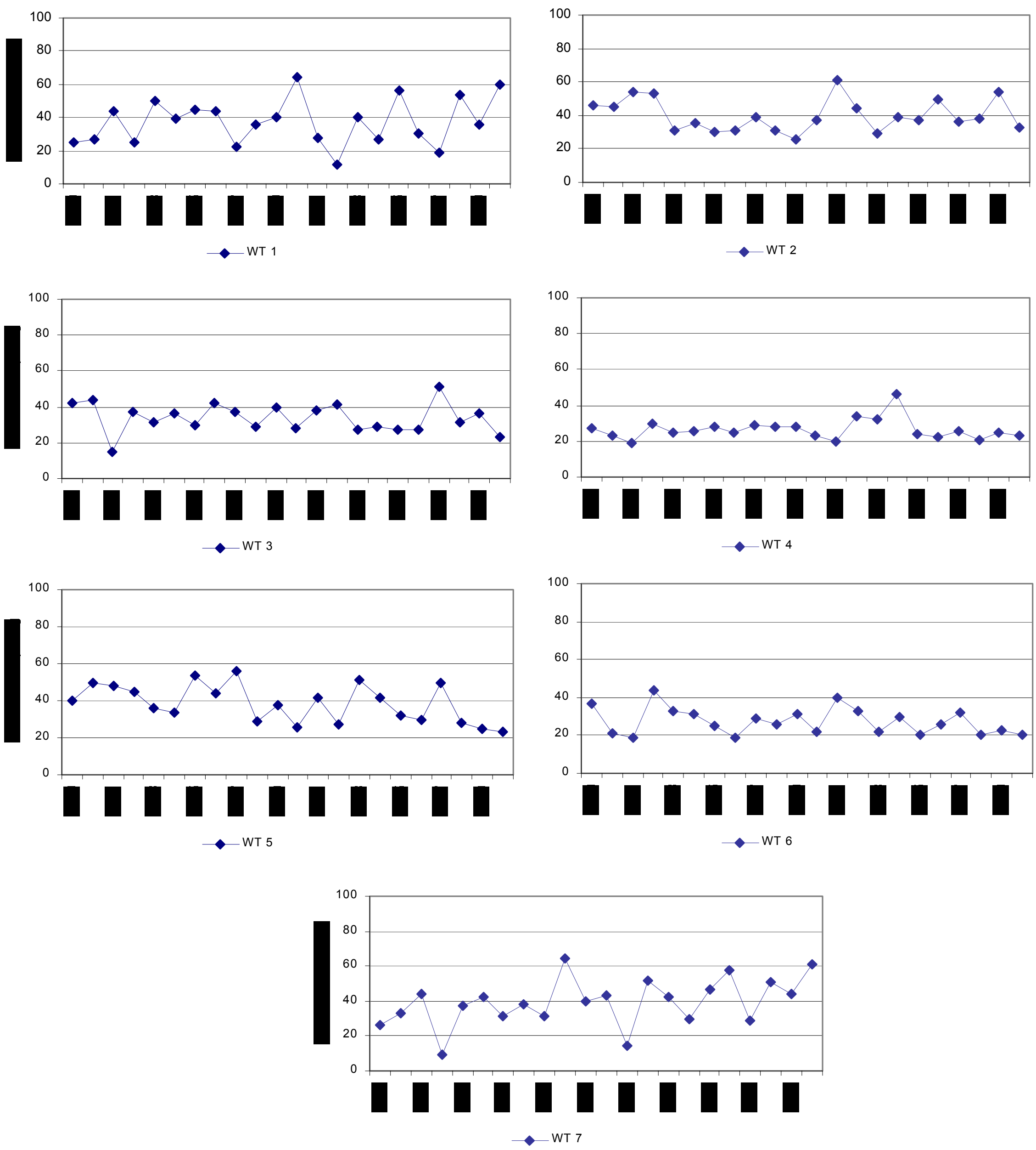

Figure 2. Time series of the number of occurrences per period (Oct to May). Each period is indicated by the initial year.

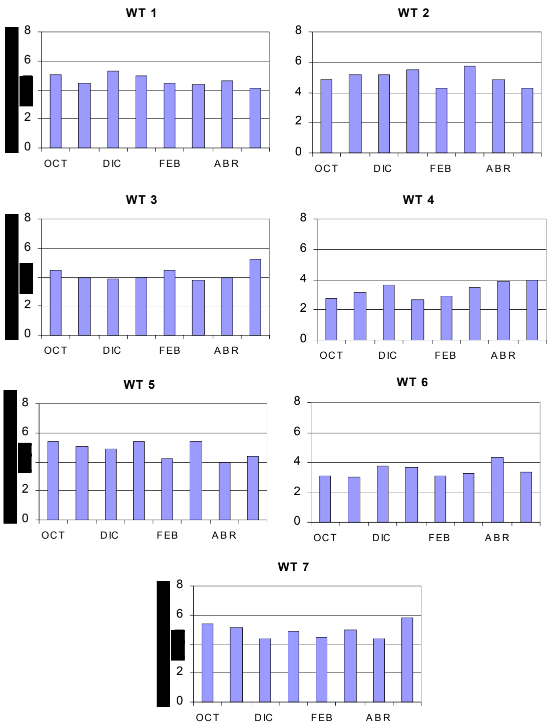

Figure 3. Monthly mean frequencies for each group of WT.

Monthly mean frequencies for each group is displayed in Figure 3. WT1 presents the highest frequencies in December in agreement with the maximum in the meridional circulation index which estimates the difference of 1000 hPa geopotential heights at 40°S between Pacific and Atlantic Oceans (Alessandro, 1998)his indicates an intense South Pacific high during this month. Situations with enhanced SE flow over central Argentina (WT3) reach their maximum during spring and fall. These situations can be associated with the SE windstorms (*sudestadas*) in the Rio de la Plata estuary and their monthly distribution is coincident with the results found by Ciappesoni and Salio (1997) and Escobar et al. (2004). WT6 presents maximum frequencies during April and summer months coinciding with Necco (1982) who found that the more frequent oceanic cyclogenesis occur during summer and transition seasons.

Not only the recurrence but also the persistence of anomalous conditions in circulation affect the local weather conditions. The persistence of each group was also analyzed (Table 2). The less persistent groups are WT4 and WT6 which represent opposite situations from the dynamical point of view (positive and negative anomalies at the east of the continent respectively). These patterns could be associated to short wave disturbances of brief duration. While WT2 and WT3, with positive anomalies of geopotential height at high latitudes, are the most persistent patterns. Whereas WT7 presents 54% of its sequences in short duration (between 2 and 4 days of extent).

Table 2. Percentage of events of given duration (d) in days.

D	WT1	WT2	WT3	WT4	WT5	WT6	WT7
1	47.6	39.8	44.2	67.5	48.2	64.2	38.8
2	26.3	25.3	24.0	24.6	24.8	23.2	31.6
3	13.0	15.5	16.3	6.4	12.3	7.6	16.3
4	6.3	8.2	5.1	0.5	7.1	2.3	6.3
5	2.3	5.7	2.2	0.5	3.9	1.6	2.8
6	2.3	2.2	1.6	0.0	1.2	0.8	2.8
7	1.3	1.6	2.6	0.5	1.7	0.0	1.3
8	0.8	0.3	1.6		0.2	0.3	0.3
9	0.3	0.3	0.6		0.2		
10		0.5	0.6		0.2		
11		0.5	0.6				
12		0.5					
13							
14							
15			0.3				

3.2 Association with rainfall episodes

At this point, the objective is to find the main spatial patterns under which significant daily rainfalls ,or no rainfall at all, tend to occur. In order to evaluate the link between the occurrence of a specific atmospheric pattern and rainfall, the Z test was applied (Infante Gil and Zárate de Lara, 1984). This test compares relative frequencies. In particular for this work, the difference between the probability of occurrence of a rainy day (heavy rainy day or dry day) given a specific pattern of WT and the climatological probability of a rainy day (heavy rainy day or dry day) was evaluated by means of the Z statistic. Z values and their significance are shown in Table 3. If Z value is positive (negative) and significant, the specific pattern of WT has (has no) significant contribution in the rainfall condition.

Groups WT1 and WT4 contribute to dry conditions over the region since they present positive and the most significant values for dry days and negative values for the others days with wet conditions. Situations with a ridge to the east of the continent (WT4) also inhibit local rainfall (not shown). Conversely, rainy days are most related to situations with E-SE advection over the Pampas region (WT3). These situations also present negative significant values of Z indicating that this pattern does not favour dry conditions. In a similar way, pattern WT6 presents a positive statistic (although not significant) for rainy days and a negative significant one for dry days. Even though heavy rainy days do not present significant values with any group, WT7 seems to be the pattern most associated with this wet condition. This result in addition with the increases in time of both precipitation over the region and WT7 frequencies fortifies the idea that low frequency changes in annual precipitation are accompanied by changes in circulation.

Table 3. Z test statistics. In brackets: relative difference with climatological frequency. Significant values at 95% (*) and at 90% (**).

	Dry Days	Rainy Days	Heavy Rainy days
WT1	**3.78* (13.2)**	**-3.24* (-31.1)**	-0.09 (-2.3)
WT2	**1.74** (6)**	0.12 (1.3)	-0.09 (-2.4)
WT3	**-3.97* (-14.7)**	**2.95* (39.3)**	0.96 (30.3)
WT4	**3.41* (13.9)**	**-1.87** (-22)**	-0.60 (-17.4)
WT5	**-2.76* (-9.6)**	**-1.76** (-17.8)**	-1.36 (-30.6)
WT6	**-3.98* (-16.1)**	1.04 (14.1)	0.47 (15.6)
WT7	0.52 (1.8)	-0.50 (-5.3)	1.21 (36.2)

In order to analyze the circulation associated with rainy and dry episodes, heavy rainy days and dry days were kept and the composite fields of geopotential height anomalies were calculated for each condition of rainfall within each group. The composite patterns for the 7 groups are presented in Figure 4. In both cases (heavy rainy days and dry days), the spatial patterns respond to the large scale spatial structure of the group they belong, even though it can be observed lower scale anomalies that make difference between the both rainfall conditions. Every group for heavy rainy days presents cyclonic anomalies in central and northern Argentina. These patterns show the biggest differences with each center of the group when it is compared with Figure 1. While spatial patterns associated with dry days show an enhanced anticyclonic anomaly over the region when this positive anomaly exists (as in WT3, WT4 and WT5) or the negative anomaly is reduced (as in WT1, WT6 and WT7).

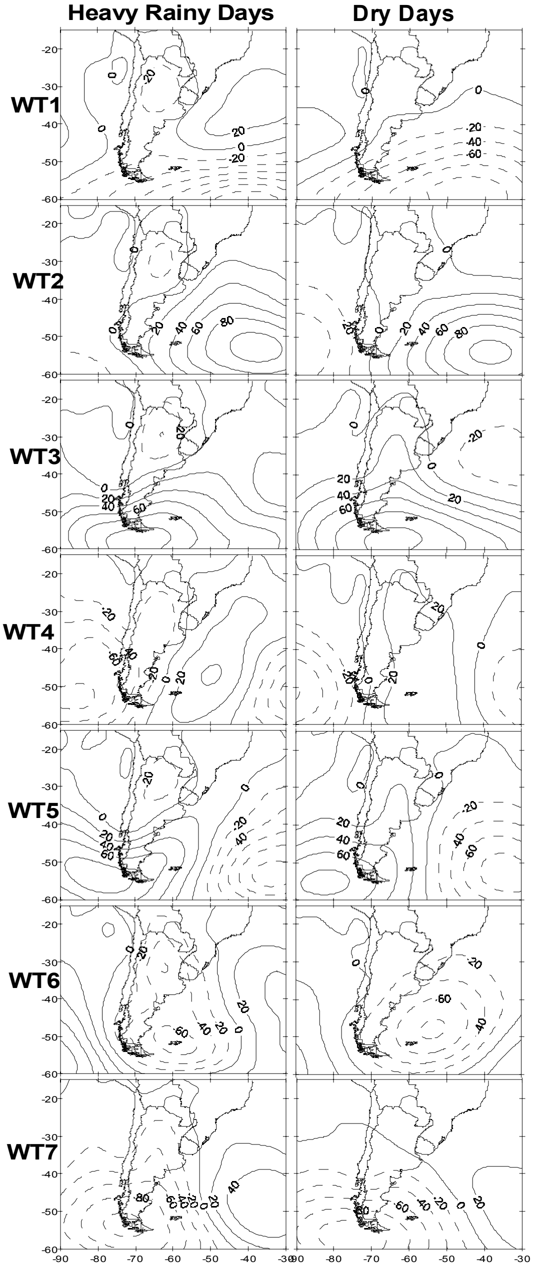

Figure 4. Composites of geopotential height anomalies for heavy rainy days (left panel) and dry days (right panel).

4. CONCLUSIONS

This paper dealt with synoptic situations represented by daily 1000 hPa geopotential fields in order to find synoptic patterns in southern South America. Principal component analysis was performed coupled with cluster analysis to determine the weather types. The seven outline spatial structures of WT obtained fit very well with the main synoptic fields recognized by forecasters.

The most outstanding results are: major interannual variabilities were found for those groups with enhanced westerlies (WT1 and

WT7) while the opposite behavior was found for those days characterized by a ridge at the east of the continent (WT4) inducing subsidence at low levels and warm advection. It was observed a progressive diminution in time of cold air advection situations (WT5) associated with an anticyclone which induces stability conditions at low levels. This result is coincident with the increase of summer minimum temperature values observed in recent decades over the studied area which depend mainly on the night-time radiative effect. An increase in seasonal frequencies of enhanced mid-latitude westerlies and disturbances migration over Patagonia (WT7) was detected with minimum frequencies during El Niño years.

The analysis of the monthly frequencies for each group displayed that situations with negative anomalies over the SW Atlantic and SW flow over the continent (WT1) presented the highest frequencies in December in agreement with the maximum in the meridional circulation index (intense South Pacific high). Situations with SE flow over central Argentina (WT3) reach their maximum during spring and fall, this is coincident with the monthly distribution of the E-SE windstorm (*sudestada*) in the Rio de la Plata estuary. The more frequent oceanic cyclogenesis (WT6) occur during summer and transition seasons.

The less persistent groups were WT4 and WT6 (positive and negative anomalies at the east of the continent respectively) which could be mostly related to short wave disturbances. While WT2 and WT3 were the most persistent groups.

Wet (dry) conditions in the Pampas region are (are not) favoured either by situations with positive anomalies over the southern tip of the continent probably associated to 'sudestadas' or by low centers in the Atlantic Ocean probably related to frontal passages or cyclogenesis. Heavy rainfall conditions are most related to situations with a disturbance in the north of Patagonia. Even though both heavy rainfall patterns and dry patterns may belong to the same cluster, lower scale anomalies make difference between both conditions. Heavy rainy days presents cyclonic anomalies in central and northern Argentina and the biggest differences with each center of the group. While spatial patterns associated with dry days show an enhanced anticyclonic anomaly over the region or a reduced negative anomaly.

Although the spatial patterns found here constitute, of course, a simplification of the complex reality, they can be useful as additional objective elements for regional forecasters. That practicality may be increased in future works in which other levels and variables could be taken into account.

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