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Surface pressure and temperature anomalies in Argentina in connection with the Southern Oscillation

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RESUMEN

La variación interanual de la presión y la temperatura en Argentina se estudia en relación con la Oscilación del Sur (OS). Se utilizaron treinta y nueve series de datos de superficie del periodo 1959-92 de la Argentina para estudiar el patrón de anomalías de la fase negativa de la OS.

La presión de superficie es menor sobre la mayor parte del país durante la fase negativa de la OS en forma estadísticamente significativa. La señal más intensa se da en el oeste del país donde normalmente y a lo largo de todo el año hay un centro de baja presión que aparece en todos los mapas medios mensuales ocupando el oeste, y centro del país. La baja del oeste (BO) tiende a intensificarse y desplazar su centro hacia el sur durante la fase negativa de la OS. Sobre el centro de Argentina la respuesta estacional varía a lo largo del año siendo en general negativa con excepción del verano. Durante el invierno alcanza su máxima expresión siendo la anomalía de cerca de 1 hPa. De acuerdo a este patrón de anomalías, excepto en el verano, el gradiente meridional sobre la Patagonia se debilita y el zonal se intensifica en el centro y Este del país. Se discute cómo este patrón de anomalías de la presión es consistente con el patrón respectivo de temperatura. En la Patagonia la fase negativa de la OS coincide con anomalías negativas de temperatura, mientras que en el centro del país, excepto en el verano, durante esta fase se observan temperaturas medias más altas aunque no significativas estadísticamente.

En el centro de Argentina, hay una marcada regularidad en el comportamiento de la presión durante el periodo de alrededor de tres años que empieza el año anterior a la fase negativa de la OS. En casi todas las fases negativas de la OS en el centro del país la presión media es menor que en al año precedente y en el siguiente. Por ejemplo, en los ocho casos estudiados, la presión durante la fase negativa de la OS fue menor que en el promedio del año anterior y el posterior. La probabilidad de que el número de secuencias observadas se produzca como consecuencia del azar es muy baja como lo demuestra su estudio con la distribución binomial. Un comportamiento similar aunque no tan regular es también observado en la Patagonia. La marcada regularidad de la respuesta de la presión a la OS en Argentina sugiere que esta respuesta está ligada a características que son comunes a todos los eventos ENSO. La interacción de la Cordillera de los Andes con la circulación anómala forzada por la convección producida durante el ENSO puede ser la responsable de la fuerte respuesta sobre la BO.

ABSTRACT

The interannual surface variability of pressure and temperature over Argentina is studied in connection with the Southern Oscillation (SO). Thirty nine surface records of the 1959-92 period from Argentina were used to study the anomaly pattern of the negative SO phase.

Surface pressure is significantly lower over most of the country during the negative SO phase. The stronger signal is over the west and center of the country where throughout the year there is a low pressure center that appears in every mean monthly map. This west low (WL) tends to be enhanced in its center to be displaced to the south during the negative SO phase. Over Central Argentina the seasonal response varies throughout the year being negative except in summer and stronger, near 1 hPa negative, in winter. According to this anomaly pattern, except in summer, the meridional gradient over Patagonia is weakened while the zonal gradient over the center and east of the country is enhanced. It is discussed how this pressure anomaly pattern is consistent with the respective surface temperature anomalies. In Patagonia the negative SO phase coincides with cooler temperatures, while in Central Argentina except in summer, warmer temperatures are observed during this phase although they are not statistically significant.

In the central part of Argentina there is a marked regularity in the pressure behavior during a period of about three years that starts in the year before the negative SO phase. In Central Argentina during almost all negative SO phases, pressure is usually lower than in the preceding and in the following year. For instance, in the eight negative SO phases studied, the pressure was lower than the average of the preceding and following year. The probability of the observed regular sequences to happen by chance was calculated with the cumulative binomial distribution and it is very low. A similar behavior, though less regular, is also observed in Patagonia. The marked regularity of the pressure response to the negative SO phase in Argentina suggests that this response is linked to features that are common to all ENSO events. The Andes mountain interaction with the anomaly circulation induced by the anomalous ENSO convection seems responsible for the strong response over the WL.

1. Introduction

Climate anomalies all over the planet have been widely studied in connection with El Niño–Southern Oscillation (ENSO). Many authors have documented the Southern Oscillation (SO) relations with climate anomalies over South America. Like in other regions, many studies have focused on the SO relation with precipitation. Hastenrath and Heller (1977), Kousky *et al.* (1984) and Rao *et al.* (1986) among others have studied the rainfall in northeast Brazil and Hastenrath (1976) in the Peruvian coast in relation to the ENSO. As for the extratropical South America, Quinn and Neal (1982) found greater precipitation in subtropical Chile and Pittock (1980a) in central Chile during the ENSO periods. Kousky and Ropelewski (1989) have studied the relationship between extremes in the SO and precipitation over South America.

Trenberth and Shea (1987) have calculated the mean annual surface pressure correlation between Darwin and locations all over the globe. They found a negative correlation coefficient of 0.2 to 0.3 over Argentina.

Pittock (1980b) found a significant negative correlation between annual surface temperature and the SO index (SOI) over central Chile and its southern coast. Halpert and Ropelewski (1992) made a global analysis of the surface temperature patterns associated with the SO. They found some connection between cooler temperatures with the positive SO phase in some months in the eastern part of Argentina, south of Brazil and over the Pacific coast from 30°S to the north, and an approximately similar result between warmer temperatures and the negative SO phase.

Aceituno (1988) has made a comprehensive analysis of the SO effect in South America climate studying the surface circulation, precipitation, temperature and pressure. Though, his main conclusions were in relation to rainfall anomaly patterns and sea surface anomalies, he also studied the relationships between the SO and the interannual variations of surface circulation through the analysis of bimonthly patterns of correlation of the SOI with pressure, temperature and wind fields. He found that during the austral winter, significant positive correlations with pressure extend from the eastern Pacific to southern South America. Also, during the positive SO phase the South Pacific subtropical high usually is enhanced and displaced poleward along the coast of Chile. With regard to surface temperature, Aceituno (1988) found a significant positive correlation with the SOI during September–October in the southermost tip of the continent with values of 0.6 at various stations.

The interannual variability of pressure and temperature over Argentina in connection with the SO is studied in this paper through the analysis of the spatial difference patterns between the positive and negative SO phases. This approach is complementary of the correlation patterns analysis done by Aceituno (1988), and will permit to see if the quasi stationary systems over Argentina have some response to the SO as happens with the South Pacific subtropical high along the coast of Chile.

While ENSO events have an important variability from one event to another, many of their main qualitative features remain the same (Rasmusson *et al.*, 1986). So, another point to be addressed in this paper is the regularity of some aspects of the surface pressure and temperature response to the SO over Argentina.

2. Data

Although recently the Argentine National Meteorological Service made available an important new set of old meteorological records, most of the daily meteorological Argentine records before 1959 are not yet available in magnetic support. On the other hand, very few stations remained unchanged either in their location or in their environment during the forties and the fifties when many of them were moved to airports and the urban growth reached some others. Therefore, we selected only thirty nine pressure and temperature series that were reliable and almost complete in the period December 1958 – February 1992 (Fig. 1). Temperature records from great cities were not used to avoid the urban growing effect influence.

On the average, the negative and positive phases of the SO do not cover the same part of the year. So, temperature and pressure anomalies were computed from departures of the 71-80 monthly averages to filter out a possible seasonal bias in the response of these parameters to the SO.

Many records have only three observations a day at main synoptic hours. Therefore, monthly averages were calculated using only 12, 18 and 24 UTC data that roughly corresponds to 8-9, 14-15, and 20-21 solar hours depending on the longitude of the station. In Argentina, these arevages are near the 24 hour average with a difference that usually is less than 1 °C in temperature and less than 0.2 hPa in pressure. Corrections to the 24 hours average depend on month and location, and are not always well known. So, it resulted more precise to work directly with three hour averages without any correction.

Mean monthly averages were computed when there were at least data from 20 days at the three selected hours. Actually, most of the incomplete months did not have observations at all and only few of the incomplete cases had more than 20 days. Quarterly anomalies were computed only when every monthly value could be calculated as explained. When these requirements were not met, data was considered absent. Series were selected only when missing quarterlies amount to no more than 10%. Missing quarterlies were interpolated from quarterly anomalies maps. Since the dominant spatial scale for both temperature and pressure quarterly anomalies seems of the order of 1000 km, very few interpolated data in a few series cannot introduce significant mistakes, even more when the subsequent analysis are based on regional averages. Most of the incomplete series retained were from the south of the country, where the sparse meteorological network did not allow a strict selection of the records.

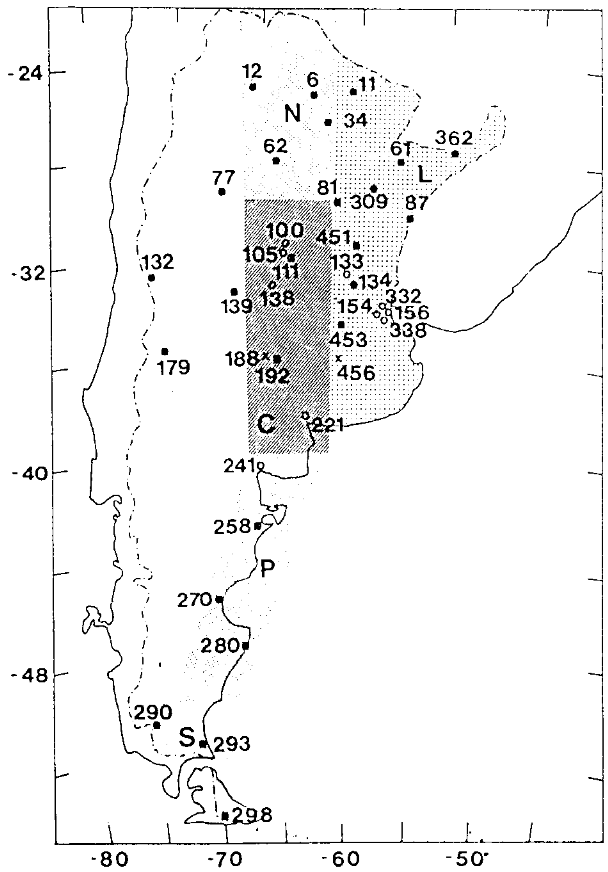

Fig. 1. Location of the stations and regions referred in the text. • Pressure and temperature, O only pressure. X only temperature.

3. Pressure and temperature anomalies and the Southern Oscillation

Several indices have been used to monitor the SO. In this paper, we use as SOI the difference of monthly anomalies between Tahiti and Darwin normalized by the overall standard deviation of the 40-year period 1941-80 (Trenberth, 1984). These data have been obtained from the World Monthly Surface Station Climatology set from the National Center for Atmospheric Research. Since the monthly SOI values may include short period fluctuations no related to ENSO events, we use seasonal averages that according to Trenberth (1976) are the shortest recommended averaging time in monitoring the SO. The negative SO phase, as it is known, is closely related to El Niño occurrence, a phenomenon that encompasses at least several months. In this paper, the negative SO phases are considered as those periods when the seasonal SOI average is less than -0.3 for at least three consecutive seasons. From now on, we call these periods the negative SO phase. They are shown in Table 2.

Before showing the pressure and temperature response to the SO in Argentina, it is convenient to introduce a short climatic background. To the north of 40°S, the circulation is frequently under the influence of the South Atlantic quasi stationary high, with prevailing light north easterly winds. Most of the time, there is a low pressure center in the western and central part of the country (WL) originated by the Andes topography and by surface heating. This low appears also in climatic maps (Fig. 2). The WL persists in every monthly climatic mean map all over the year although it is less intense in winter (Hoffmann, 1993; Taljaard *et al.*, 1969). This pattern is often modified by polar front irruptions from the South. These irruptions are less frequent in summer when many fronts do not progress north of the 40° to 35°S latitude band. To the south of 40°S, the circulation is very intense and persistent from the West, and only occasionally is altered by deep perturbations of the west flow.

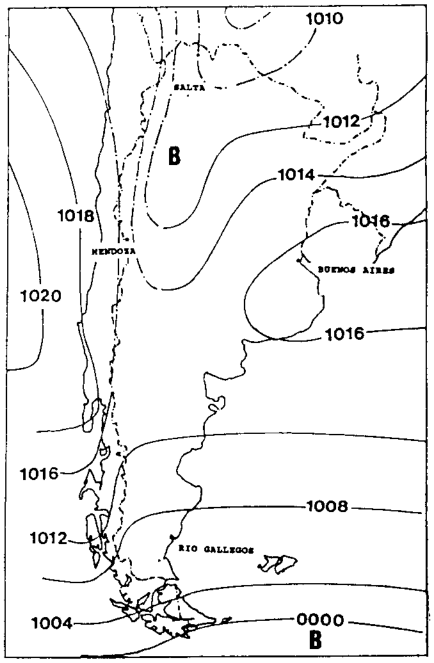

Fig. 2. Mean annual sea surface pressure. After Hoffmann (1993).

Figure 3 and 4 depict the average surface pressure and temperature differences over the Argentine territory between the nine negative SO phases of January 1958 – February 1992 and the rest of the period. Pressure is lower on the average during the negative SO phase over the whole country showing a minimum over Mendoza and the Northern Patagonia (Fig. 3). In the eastern part of the country, there is also a relative minimum, but less intense than in the West. According to this, the WL is on the average deeper and displaced to the south during the negative SO phase. Since the pressure negative anomalies diminishes to the south, there is less meridional gradient, and consequently it should be less zonal wind over Patagonia. Also, west of 62°W there is an increase of zonal gradient which may in turn enhance the warm advection. In fact, the temperature difference map shows a maximum of 0.3°C in that area (Fig. 4).

North of 40°S, temperature is 0.1 to 0.3°C warmer while south of this latitude this difference becomes smaller and south of 45°S negative with a minimum at Rio Gallegos of – 0.7°C. It is precisely to the south of 40°S, that Aceituno (1988) found the stronger and significant positive correlation between temperature and SOI during the early spring. South of 45°, except in a few locations, the annual average surface wind speed ranges from 7 to 10 m/s (Barros, 1986). In this region, the vertical mixing controls the nocturnal cooling in most of the frequent windy nights. Under this conditions, the lower meridional gradient associated to the negative SO phase implies, in this region of prevailing zonal circulation, a lower wind speed and therefore a better chance for nocturnal cooling.

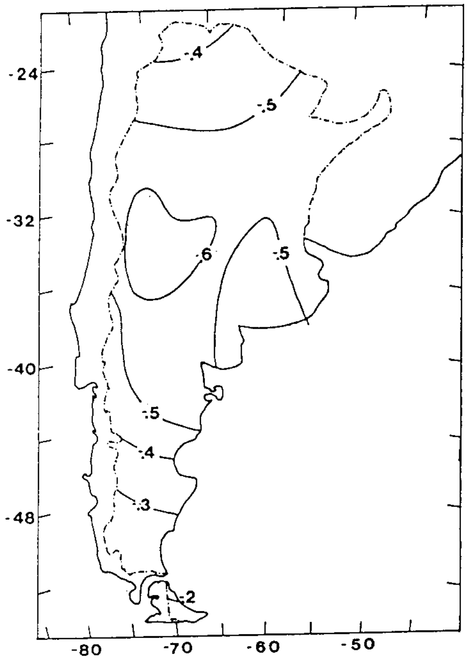

Fig. 3. Pressure differences between ENSO and no ENSO years. Lines every 1 dPa.

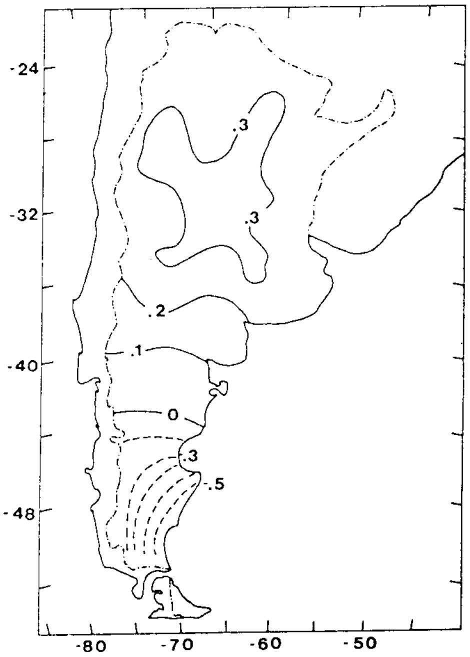

Fig. 4. Temperature differences between ENSO and no ENSO years. Lines every 0.1 °C.

The question now is if the averaged patterns shown in Figure 3 and 4 are consequence of a regular behavior in most of the SO cycles, or on the contrary, they are the result of very strong patterns in only some cases, either in the negative SO phase or in the other phase. Figure 5 shows the time evolution of pressure anomalies in a meridional cross section from 24° to 55°S. All series from stations between 62° and 66°W were projected by latitude. From 46°S to the south, stations to the west of 66°W were included. The stations used in the meridional cross section are those in the N, C, P and S regions shown in Figure 1. Anomalies usually reached 10 to 30 degrees in latitude and persisted more than could be expected if they were statistically independent. This point will be analyzed in other paper by the authors, and it is only mentioned here. Figure 6 shows the same cross section for temperature. Spatial and time scales seem similar to those of pressure. In both figures, the nine negative SO phases of the 1959-1992 period are indicated. It can be appreciated that almost all negative SO phases coincide with a relative minimum in time of pressure anomalies. Also to the north of 40°S, they often coincide with a relative maximum of temperature.

The differences in the behavior of some anomalies in the regions to the north and south of 40°S may very well reflect the different circulation over both regions. According to the different circulation features and to the behavior shown in Figures 5 and 6, series were averaged in two regions. The boundary between these regions was chosen at 40°S. From now on, they will be called C (Central) and P (Patagonia) regions, Figure 1. The C region extends only to 30°S to the north and to 66°W to the west, to avoid distortions introduced by the altitude of some stations, like Salta and Mendoza. These stations, with altitude of around 1000 m or more, may have a different pressure variability from that of near sea level stations. This different behavior is not always filtered out by using anomaly series. The C region is also bounded to the east to 62°W to retain the WL behavior. In the pressure case, the P region extends from 40° to 50°S, because south of this latitude, anomalies show a different pattern (Fig. 5). For temperature analysis, it is convenient to avoid great city records, which can be contaminated by urban growth and may introduce a distortion in the analysis. Because of this, and to the lack of other temperature records, only three series would remain in each region. Therefore, for temperature, the regions were enlarged by merging the N and C regions in one and the S and the P regions in another.

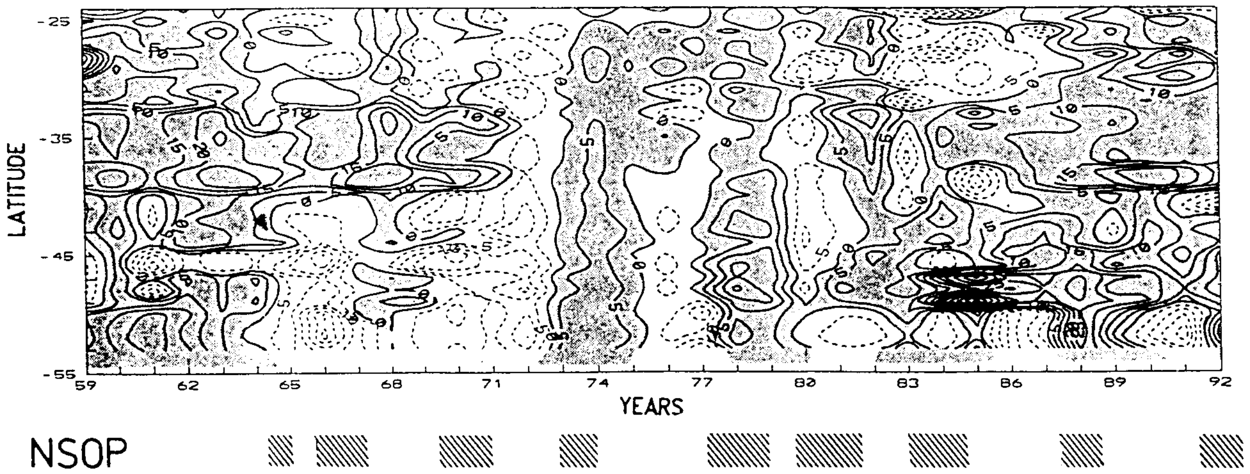

Fig. 5. Quarterly anomaly pressure cross section based on stations 6, 12, 62, 100, 105, 111, 138, 192, 221, 241, 258, 270, 280, 290 and 298. Lines every 5 dPa. Positive anomalies are shaded.

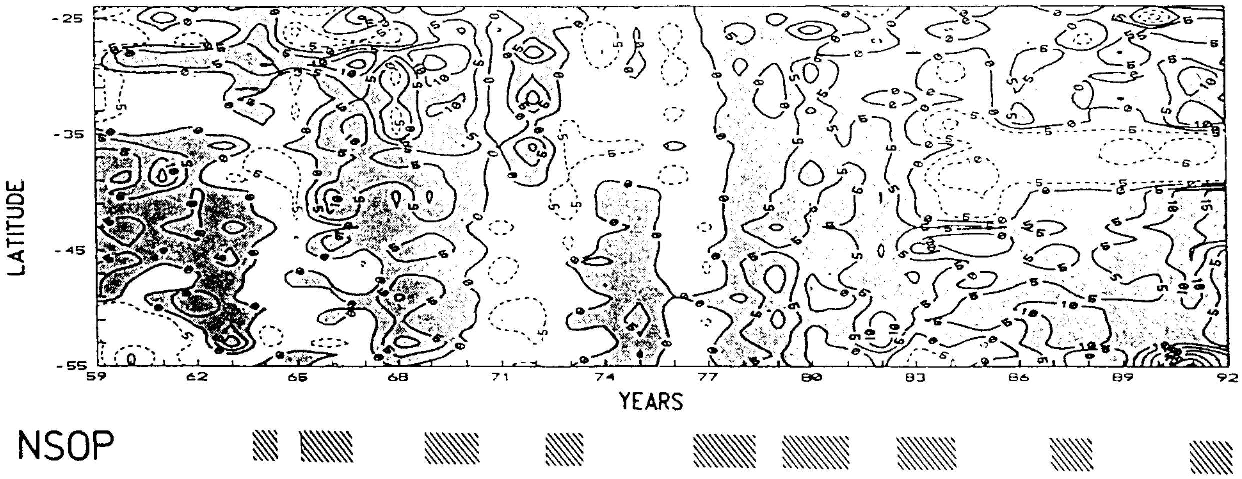

Fig. 6. Quarterly anomaly temperature cross section based on stations 6, 12, 34, 62, 111, 188, 192, 258, 270, 280, 290, 293 and 298. Lines every 0.5°C. Positive anomalies are shaded

Table 1 shows the average seasonal regional pressure and temperature anomalies. During the negative SO phase, in the N&C region, winter temperature was 0.6°C warmer, while in summer it was 0.3 cooler and in the autumn and spring had only small differences. This results are in qualitative agreement with the SOI–temperature correlation (1948-1983) in this region that was negative during May–August and positive over the whole region only in November–December (Aceituno, 1988). Average pressures during the negative SO phase in the C region were, 0.6 hPa and 0.9 hPa lower in autumn and winter, only 0.4 hPa lower in spring, and 0.4 hPa higher in summer. Again, there is a qualitative agreement with the correlation pattern found by Aceituno (1988) that is positive from May to October and negative in January–February. In the P region, pressure differences were similar to those of the C region during autumn and winter.

Table 1. Seasonal pressure and temperature regional anomalies

Region		Pressure (hPa)		Temperature (°C)	
		C	P	N&C	P&S
Negative SO phase	S	0.4	-0.3	-0.1	0.3
	A	-0.4	-0.7	0.4	0.2
	W	-0.1	0.2	0.4	0.1
	Sp	-0.1	0.1	0.0	-0.1
Non negative SO phase	S	0.0	-0.2	0.2	0.4
	A	0.2	-0.4	0.2	0.1
	W	0.8	0.9	-0.2	0.5
	Sp	0.3	0.1	-0.0	0.2

Table 2. Regional pressure and temperature anomalies of the negative SO phases, and of their preceding and following year. When the SO phase lasts less than a year, during the preceding and following years a similar seasonal period is considered. When the SO phase lasts for more than a year, the weight of the repeated seasons are 0.5. Negative SO phase are marked with asterisks.

Region	Pressure (hPa)		Temperature (°C)	
	C	P	N&C	P&S
Periods				
W 62 - S 63	3.1	1.8	-0.1	1.0
W 63 - S 64*	0.9	-0.9	0.0	-0.5
W 64 - S 64	0.1	0.3	-0.2	-0.2
S 64 - Sp64	0.5	0.3	-0.2	-0.2
S 65 - A 66*	-1.2	-1.8	0.3	0.0
W 66 - A 67	-0.2	-0.8	0.5	-0.2
Sp67 - W 68	1.3	0.8	0.3	0.6
Sp68 - S 70*	0.0	-1.1	0.4	0.0
A 70 - S 71	0.4	0.5	0.3	-0.1
A 71 - S 72	0.1	-0.7	0.4	-0.2
A 72 - S 73*	-0.4	-0.5	-0.1	-0.4
A 73 - S 74	0.6	0.9	-0.7	-0.1
S 76 - Sp76	0.0	-0.6	-0.3	-0.1
S 77 - S 78*	-0.2	0.3	0.2	-0.1
A 78 - S 79	0.4	0.5	0.5	0.8
S 79 - Sp79	0.2	0.2	0.4	0.8
S 80 - Sp80*	-0.1	-0.7	0.2	0.0
S 81 - Sp81	0.3	0.1	0.1	0.5
A 81 - S 81	0.3	0.1	0.1	0.5
A 82 - W 83*	-0.8	-0.4	0.3	0.0
Sp83 - W 84	0.1	- 0.5	-0.4	0.3
Sp85 - W 86	-0.3	0.1	0.3	0.8
Sp86 - S 88*	-0.3	1.2	0.0	0.5
A 88 - S 89	0.5	0.6	0.1	0.5
Sp89 - W 90	1.5	1.2	0.0	0.8
Sp90 - S 92*	-0.1	- 0.5	0.5	0.8

To study the regularity of the anomaly cycle, it is convenient to consider the influence of the seasonal differences. So, in Table 2 the average anomalies of the negative SO phases are presented together with the average anomalies of similar seasonal periods before and after its occurrence. When the negative SO phase extended for more than a year, the weights of seasons that were repeated in the same negative SO phase were taken as 0.5 to avoid a seasonal bias in the calculation of the averages of the negative SO phase. Comparison of the negative SO phases with their former and following years, minimizes the potential influences of other signals of lower frequency than that of the SO. For instance, the remarkable negative pressure trend over the 35° – 40°S band is an example of lower frequency (Fig. 5).

Inspection of Table 2 permits to confirm the perception from Figures 5 and 6 that almost all negative SO phases coincide with a relative minimum in time of pressure and in region N&C often with a relative maximum of temperature anomalies. These features are illustrated in Table 3 that shows the observed number of certain sequence pattern in the period that starts one year before the negative SO phase and finish a year after it. According to the cumulative binomial distribution, the high frequency of occurrence of some of these sequence patterns cannot be atributed to mere chance. In the C region, it is highly probable to have higher pressure during the year before the negative SO phase than during this phase. This also can be said of the higher presssure during the year following the negative SO phase. Because of the frequent occurrence of both sequences, with high probability the average pressure during the negative SO phase is lower than the average of the preceding and the following year. For the same reason, there is a frequent occurrence of a cycle with lower average pressure during the negative SO phase than during both, the preceding and the following year, which cannot be attributed to chance. In the region P, a tendency to similar sequence patterns is observed, although this is not so clear as in the region C. The same is also valid for temperature in both regions; there is a tendency to a cycle with a warmer phase during the negative SO phase to the north of 40°C, region N&C, and a stronger tendency to lower temperature during the same phase to the south of this latitude, region P&S. In the region N&C, the annual signal during the negative SO phase is small because of the opposite signs of the anomalies in winter and summer.

4. Discussion

As it was shown in the former section, the stronger signal during the low SO periods over Argentina is in winter, both in surface pressure and temperature. The hemispheric composite winter 300 hPa height anomalies pattern for the ENSO events years of 1972, 1976/77 and 1982, calculated by Karoly *et al.* (1989) shows a negative anomaly over Argentina, Chile and the surrounding oceans from 30°W to 90°W with a central value of -30 m over the Argentine coast at 50°S.

Surface winter temperature and pressure anomalies for these three ENSO periods were calculated with respect the the same climatic period as in Karoly *et al.* (1989). While the average value over the P region at 300 hPa was – 20 m that corresponds to -0.6 hPa, the surface anomaly of these three ENSO periods, in that region was only -0.3 hPa. According to this, the Patagonia surface pressure anomaly seems only a residual of a stronger anomaly at 300 hPa. Although this result is very limited in space to arrive to a conclusion, at least, it is consistent with the idea that the anomalous Southern Hemisphere stationary waves associated with the SO are the consequence of a barotropic Rossby like wave propagation from low latitudes (Karoly *et al.*, 1989).

In a recent paper, Grimm (1992) made a complete formulation of the forcing function as proposed by Sardeshmukh and Hoskins (1988) in a barotropic model. She calculated the influence functions for each main positive and negative anomaly centers of the Western Southern Hemisphere winter ENSO pattern. She found that an anomalous divergence in the 200 hPa level over the tropical eastern Pacific produces a negative anomaly over South Argentina and Chile at the same level height, very similar to the one observed by Karoly *et al.* (1989). Therefore, the barotropic Rossby wave propagation from low latitudes seems an explanation for the anomaly SO surface pressure pattern over Argentina south of 40°S, although it does not completely explain the observed anomalies north of 40°S. In fact, in the C region the 300 hPa anomaly for these three ENSO winter was less than 10 m negative on the average, or -0.3 hPa while the negative surface pressure anomaly was – 0.7 Hpa.

To understand how the surface pressure responds to the ENSO forcing in the C region, it is convenient to review some aspects of the WL functioning. For this, we follow Lichtenstein's analysis (1982). The WL is intermittent. It is usually present when the polar front is south of it, and disappears for one or two days after each frontal irruption to the north of its latitude. The WL deepens as the 500 hPa troughs approximates the Andes from the west, and fills up after their passage. It is important to stress that the surface intensification of the WL is not a merely barotropic response to the trough approach in the upper and middle troposphere since normally the surface pressure variation is twice the 5000 m pressure variation. Another important feature to mention here, is that the WL has a warm troposphere due to forced subsidence by the Andes.

Coming back to the winter composite anomaly of the three ENSO periods in the C region, the surface intensification of the negative anomaly with respect to the 300 hPa level seems the climatic result of the described WL response to the more frequent and intense troughs, which can be expected according to the mean 300 hPa anomaly pattern. This surface intensification also means, as in the expected WL response to this pattern, a warm troposphere structure of the anomaly over this region. The WL intensification during ENSO periods explains not only the average response, higher than what could be expected according to a barotropic response, but also explains the regularity of this signal in every SO cycle evidenced in Tables 3 and 4.

Table 3. Sequences and differences between the negative SO phase and their preceding and following year as defined in Table 2.

Number of total cases	Regional averages in each period	Pressure		Temperature	
		C	P	N&C	P&S
		Number of observed sequences			
9	Yb > nSOp	8 (0.02)	6 (0.25)	3 (0.25)	7 (0.09)
8	Ya > nSOp	7 (0.03)	6 (0.14)	3 (0.36)	6 (0.14)
8	½(Yb+Ya)> nSOp	8 (0.004)	6 (0.14)	2 (0.14)	7 (0.03)
8	Yb > nSOp < Ya	6 (0.004)	4 (0.11)	1 (0.36)	5 (0.03)
8	Yb < nSOp > Ya	0 (0.10)	1 (0.36)	3 (0.87)	1 (0.36)
		Mean difference			
9	nSOp - Yb	-0.8(0.01)	-0.8(0.1)	0.1(--)	-0.4(0.05)
8	nSOp - Ya	-0.5(0.01)	-0.7(0.05)	0.2(--)	-0.3(0.1)
8	nSOp-½(Yb+Ya)	-0.6(0.01)	-0.7(0.1)	0.1(0.2)	-0.4(0.02)

Yb: preceding year before the negative SO phase (nSOp); Ya: the following year after the negative SO phase. Numbers in brackets are the cumulative binomial probability for equal or greater number of outcomes than the observed number, except in the N&C column and in the Yb < nSOp > row where it stands for equal or lower number of outcomes than the number observed and in the last three rows where they are the level of significance.

Surface temperature is throughout the year negatively correlated with the SOI over most of tropical South America (Aceituno, 1988). According to him, this can be related to the general response of the tropical troposphere to surface water temperature in the tropical Pacific

(Angell, 1981). North of 40 S over Argentina, the circulation favors the frequent advection from tropical South America and so, the warm anomalies over this region observed during the negative SO phases throughout the year with the exception of the summer, may contribute to similar anomalies over Argentina.

Table 4. Correlation coefficients between quarterly pressure and temperature regional averaged series. In brackets the percent level of significance. Regions are described in the text.

	Temp. N&C	Temp. L	Temp.P&S	Pres. C	Pres. P
Temp. N&C	1.0	0.85 (0.1)	0.27 (1)	-0.37 (0.1)	-0.35 (0.1)
Temp. L	-	1.0	0.24 (1)	-0.42 (0.1)	-0.32 (0.1)
Temp. P&S	-	-	1.0	0.35 (0.1)	0.28 (1)
Pres. C	-	-	-	1.0	0.60 (0.1)
Pres. P	-	-	-	-	1.0

On the other hand, the WL response to the SO reinforce this effect on the temperature and help to explain the summer exception. The intermittent WL behavior together with the lower interdiurnal variance of the western part of the Atlantic height causes a pronounced variability of the meridional pressure gradient to the east of its center and therefore of the temperature advection from the north. Then, the WL pressure anomalies should influence the temperature anomalies on the central and eastern part of Argentina. It is true that the WL intermittence itself leads to a negative correlation of temperature and pressure in its area of influence because the lower (higher) pressure phase is usually associated to the polar front position to the south (north) of the region and the warm advection is one cause of its intensification (Lichtenstein, 1980). Table 4 shows the quarterly correlation coefficient between pressure of regions C and P and temperatures of the regions N&C, P&S and L. As expected from the previous comments, C pressure is negative correlated with both L and N&C temperatures. The negative correlations are perhaps not higher due to the complex processes that influence the surface air temperature as, for instance, wind intensity and cloudiness. In contrast, south of 40°S, the pressure has a positive correlation with temperature. The long meridional pattern of pressure anomalies (Fig. 5), explains the positive correlation between the pressure of both regions. This correlation is higher than the respective correlation between the regional temperatures, that are differently influenced by the WL.

After this brief discussion, it seems plausible that the association between the negative SO phase and the warm temperature in Argentina to the north of 40°S in winter could be partially explained by the lowest pressure anomaly over the WL. In summer, the average pressure anomaly is positive in this region. Consistent with the former arguments and the correlations calculated, the temperature anomaly in summer is negative (Table 1). Because of the different anomaly sign in summer and in the rest of the year, the annual temperature anomaly of the negative SO phase is very small and not significant in this region.

It is convenient to stress the climatic importance of the WL in Argentina and neighboring countries. When it becomes more intense the moist and temperature advection from the north increase. Lichtenstein (1980) showed its relation with precipitation due to squall lines and cyclogenesis in the eastern part of subtropical South America. Though, the rainfall is not discussed here, the WL intensification during fall and winter of the negative SO phase may contribute to the enhanced rainfall shown by Aceituno (1988) in eastern Argentina and southern Brazil during May–June. Nevertheless in this region the stronger rainfall signal is during summer (Ropelewski and Halpert, 1987) when the WL is less intense and so, its contribution to the annual rainfall should be negative.

5. Conclusions

During the negative SO phase, surface pressure is lower over Argentina with the stronger signal over the south of the WL. According to this, the WL tends to be enhanced and its center to be displaced to the south during the negative SO phase. During the negative SO phase the WL troposphere becomes even warmer than usually as can be inferred from its smaller geopotential response in the middle troposphere. The Andes mountain interaction with the anomaly circulation induced by the anomalous ENSO convection in the Pacific seems responsible for the strong signal in Central Argentina. As for the seasonal behavior of this response, negative surface pressure anomalies over the whole country are stronger in winter, near 1 hPa, and weaker in summer when they are positive in Central Argentina.

In Patagonia the negative SO phase coincides with cooler temperatures. In Central Argentina the surface temperature response to the SO cycle is not statistically significant. Still, the seasonal response coincides with what should be expected from the negative SOI correlation over the tropical South America throughout the year except in summer. This exception can be explained by the pressure seasonal response, that favors the observed warm anomalies during winter and cool anomalies in summer.

The signal over Argentina appears not only in the anomalous mean negative SO phase but also in almost every case. Specially in the central part of Argentina there is a marked regularity in the pressure behavior during a period of about three years that starts in the year before the negative SO phase. This regularity is higher than what could be expected from the somewhat low annual correlation coefficient (-0.2 to -0.3) between the regional pressure and Darwin pressure (Trenberth *et al.*, 1987), and the wide variability between ENSO events. A tendency to a similar cycle, is also observed in the Patagonia surface pressure anomalies. This regularity could be an indication that the nature of the surface pressure response over Argentina to the negative SO phase may be linked to features that are common to all ENSO events. Due to the connection of the climatic pressure pattern with temperature and rainfall, specially in the case of the WL, this sequence response to the negative SO phase appears as an interesting possibility for climatic forecast in the region.

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