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Sequence patterns of 1000 hPa and 500 hPa geopotential height fields associated with cold surges over Central Argentina

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RESUMEN

En este trabajo se realizó una clasificación objetiva de secuencias de campos de altura geopotencial en 500 hPa y 1000 hPa asociadas a irrupciones de aire frío en el centro de Argentina. Las irrupciones de aire frío que ocurren durante el invierno (mayo a septiembre) en el centro de Argentina provocan daños importantes en la agricultura y a veces afectan al sector energético. En particular, el consumo de gas natural es fuertemente dependiente de los descensos significativos de temperatura. Para obtener los Patrones de Secuencias Principales (PSP) de 1000 hPa y 500 hPa se utilizó el Análisis por Componentes Principales (ACP) rotadas. Las irrupciones de aire frío de invierno durante el período 1979-1993 se identifican con siete modelos patrones en 1000 hPA y tres modelos en 500 hPa. La combinación de ambos niveles muestra tres situaciones típicas asociadas a irrupciones de aire frío en el centro de Argentina. El patrón de circulación más clásico muestra una importante cuña en altura en el océano Pacífico al oeste del continente sudamericano y un anticiclón post-frontal en superficie provocando advección de aire frío sobre Argentina central. Los restantes modelos patrones muestran una vaguada de onda larga en altura afectando el continente, uno de ellos con el anticiclón post-frontal moviéndose en latitudes medias y bajas y el otro con un anticiclón migratorio afectando latitudes más bajas.

ABSTRACT

An objective classification of sequence patterns of 1000 hPa and 500 hPa geopotential heights associated with cold surges over Central Argentina was carried out. Polar Outbreaks during wintertime in Central Argentina (May to September) cause important damage to the regional agriculture and sometimes affect the energy supply. In particular, the consumption of natural gas is strongly dependent on significant temperature descents. The rotated Principal Components Analysis (PCA) was used to obtain the basic patterns of sequence of 1000 hPa and 500 hPa geopotential heights. The winter cold surges during the 1979-1993 period occur in seven patterns at 1000 hPa and three modes at 500 hPa. The combination of both levels shows three typical situations related to cold surges over Central Argentina. The most classic pattern shows an important ridge west of the Pacific coast of the continent at its upper level and a postfrontal anticyclone at its lower level producing cold air advection over Central Argentina. The other two patterns present a long wave trough at upper levels affecting the continent, one of them with the postfrontal anticyclone moving over middle and low latitudes, and the other with the migratory anticyclone affecting lower latitudes.

Key words: Cold surges, Principal components, Blockings

1. Introduction

Cold surges are frequently observed during the winter season (May to September) in Central Argentina, producing substantial damages to regional agriculture and to energy consumption. Most of them are associated with the passage of a midlatitude wave in the middle-troposphere that interacts with the Andes cordillera and propagates toward the equator reaching low-latitudes. When a cold event occurs in Central Argentina the meteorological situations are linked to the passage of midlatitude disturbances such as cold fronts that move from the Pacific Ocean. After the cold front hits, a migratory anticyclone, moves over the continent producing important temperature drops.

Most of the literature related to cold surges is based on descriptive studies of individual cases, especially those with strong incidence on South America (Marengo *et al*., 1997; Fortune and Kousky 1983; Scian, 1970).

Some results are connected with the mean structure and evolution of winter disturbances associated with cold surges over South America. Escobar and Bischoff (1999) made an objective classification of 1000 and 500 hPa geopotential heights related to significant temperature drops in Buenos Aires. Two dominant patterns were found: one has an intense anticyclone with a northwest-southeast axis and a maximum strength near 80°W, 40°S. This pattern produces south / south - easterly winds over Buenos Aires. The other pattern shows a high-pressure system at 105°W, 48°S associated with blocking situations over the Pacific Ocean, which results in persistent southerly winds over Buenos Aires.

Garreaud (2000) documents the mean three-dimensional structure and evolution of cold surges over South America using a compositing analysis. To select the cold episodes he used the 24-h sea level pressure tendency in a 5° x 5° grid box centered at 25°S, 57.5°W; additionally employing 17 years (1979-1995) of atmospheric reanalysis fields (NCEP/NCAR) and extracted a total pool of 145 wintertime cases (May- September). The analysis of the composite fields shows a mid-latitude wave, with a ridge to the west of the Pacific coast and a trough extending south-eastward from the subtropics into the South Atlantic.

Nocera *et al*. (2000) made a climatologic and compositing study of cold surges in South America using data from NCEP/NCAR reanalysis. 1000 hPa heights and 1000-850 thickness contours for a five year period (1992-1996) were analyzed. The cold surges were classified into four types and most of them were broken up into categories of strong, moderate and weak intensity. The most powerful cold air incursion was associated with a trough (at upper levels) over the east cost of

South America and a ridge to the west. In this kind of pattern, the anticyclone reaches low latitudes, producing an important push of cold air from higher latitudes.

As mentioned above, most of the papers related to cold surges in South America deal with the analysis of composite fields, producing a comprehensive climatology of this kind of episodes. We are also interested in identifying different synoptic situations involved as well as their frequency. Therefore, the purpose of this paper is to find the most dominant synoptic-scale modes of circulation associated with cold surges over Central Argentina. The final objective of this paper is to study the propagation of cold waves by tracking migratory anticyclones that push cold air into Central Argentina. Thus, an objective classification of sequence patterns of 1000 hPa and 500 hPa geopotential heights associated with cold surges over Central Argentina was conducted.

The paper is organized as follows: description of the data is presented in Section 2; the methodology of the Principal Components with their particular approach is discussed in Section 3. Sections 4 to 6 show the results obtained, and the conclusions are presented in Section 7.

2. Data

The analyses in this research are based on 15 years (1979-1993) of atmospheric reanalysis from the European Centre for Medium Range Weather (ECWMF). The data are set on a 2.5° x 2.5° latitude/longitude grid, and the reanalysis include daily (12 UTC) geopotential heights at 1000 and 500 hPa. The area under study is bounded between 20° and 60°S, and 40° to 130°W and the period includes the months from May trough September.

Furthermore, daily temperature maximums and minimums, from the Buenos Aires Central Observatory (OCBA – 34.6°S, 58.4°W) were used. These correspond to the months from May through September, between 1967 and 1996. These data were provided by the Argentine National Weather Service.

3. Methodology

Since the magnitude of temperature decrease is one of the best-defined features of cold outbreaks, the mean daily temperature difference was selected to identify cases related to cold episodes. If the prevailing temperatures before the arrival of cold air are above the mean, the thermal contrast will be enhanced and the temperature difference will be significant. Therefore, to ensure that the relevant temperature decrease was actually associated with the advance of a strong cold front, it was necessary to also consider the mean daily temperatures for the previous and subsequent days. For this reason, the criterion of Escobar and Bischoff (2001) was used to select the days associated with cold episodes. It is based on the interdiurnal descents of mean daily temperature and the prevailing thermal conditions on the day before the descent and on the day of the descent, respectively.

Event selection was determined according to the following conditions:

a) The interdiurnal descents of mean daily temperature must be greater than a certain threshold of temperature (approximately 4 °C for Buenos Aires City).

b) Mean daily temperature on the day before the descent must be above the mean value.

c) Mean daily temperature on the day of the descent must be above below the mean value.

The criterion was applied to the Buenos Aires Central Observatory to consider a place referring to the center of the country.

Using these criteria, the synoptic situations at 1000 and 500 hPa were used to select 100 events for the analysis.

The Principal Component Analysis (PCA) in T-Mode using correlation input matrix was applied (Green and Carol, 1978; Richman, 1986). The mathematical equations and some important properties of the methodology can be found in Richman (1986). Then, the Principal Sequence Patterns (PSP) of 1000 and 500 hPa geopotential heights (Compagnucci *et al*., 2001) were obtained. In this application, each variable is a sequence of the consecutive spatial patterns of geopotential height, where the first day corresponds to the day of the event and the correlation matrix corresponds to a correlation between sequences.

Then, a varimax rotation retaining seven and three principal components (PCs) was applied to separate signal from noise on real data. To select theses numbers of components the eigenvalue 1.0 rule was used (Richmann *et al*., 1992).

4. Geopotential height at 1000 hPa

The analysis gave seven basic patterns of sequences that explain 70% of the variance. The Principal Sequence Patterns (PSP) corresponds to sequences of circulation patterns accounting for decreasing variance (Table 1). The analysis of the component loading (figures not shown) lets us evaluate the representative patterns as real synoptic situations; values closer to 1 represent sequences of meteorological situations similar to the obtained pattern sequence (Harman, 1976; Cattell, 1978). The first four loading components show values greater than 0.7. This means that theoretical pattern sequences and real synoptic situation have a similar configuration. For this reason, the structure and the temporal evolution of the synoptic situations related to the first four PSP was carried out. The remaining PSP are less representative and are not consider within this description since their explained variance is not significantly different to 0.

Table 1. Percentages of variance explained and cumulative percentage explained by the seven components.

PSP	PER. VAR.(%)	PER. CUM. VAR. (%)
1°	18.4	18.4
2°	16.8	35.2
3°	14.4	49.6
4°	9.7	59.3
5°	4.4	63.7
6°	3.4	67.1
7°	2.8	69.9

Theoretical PSP modes could be related to the two possible patterns of circulation. One of them (the direct mode) corresponds to the system with the same sign as the PSP mode, that is to say high pressure in the system with positive values and low pressure in the system with negative values. The inverse pattern is not a real situation associated with cold surges because it was not found in any case. Figures 1 to 4 show the first four PSP and examples of actual circulation fields sequences which have a factor loading greater than 0.7 with each of the sequences' patterns.

PSP 1 is shown in the left panels of Figure 1 where the three frames corresponding to day –2 in the top, day –1 in the middle and day 0 (related to the day when the temperature drops over the city) in the bottom. This PSP explains 18.4 % of the variance, and shows the most frequent temporal evolution of the synoptic situations related to cold surges over Central Argentina.

Two days before (day –2) the cold air mass hits Buenos Aires, an intense anticyclone can be observed over the South Pacific Ocean centered in 50°S, 90°W as it begins to move into Argentina. The day when the temperature drops over the city (day –0) the migratory system reaches the southern Patagonia leading to south / south-easterly winds over Buenos Aires. At the same time, a region of low pressure extends from the northeastern part of the area toward the South Atlantic on a north / northwest to south / southeast axis, with the minimum value over the southern Atlantic Ocean. This feature is associated to the passage of a cold front over Argentina.

The right panels in Figure 1 show real sequences of surface charts from 12 UTC 29 August 1991 to 12 UTC 31 August 1991, when the mean daily temperature dropped 5.5°C. The correlation coefficient between this actual situation and the PSP 1 is 0.77, and shows agreement with the theoretical patterns.

PSP 2 (left panels in Fig. 2) explains 16.8 % of the variance and shows a high pressure system extended over the Pacific Ocean that moves slowly eastward during the three days, while it intensifies showing the highest values at day –0. At the same time, a trough was observed over the Atlantic Ocean related to the synoptic perturbation that advances over the study region. Both, the anticyclone in the Pacific Ocean and the cyclone in the Atlantic Ocean, produce south / south-westerly flow over the center of the country with a strong cold temperature advection.

The right panels in Figure 2 show real sequences of surface charts from 12 UTC 23 August 1988 to 12 UTC 25 August 1988. In such situation, the mean daily temperature decreased 7.2°C.

In the Pacific Ocean the structure of a great quasistationary anticyclone over 110°W producing anticyclogenesis over the continental area can be observed. At the same time, a low-pressure system located in the South Atlantic Ocean over 60°W moves eastward while intensifying. The conjunction of both systems produces cold air advection from the south / southwest direction that enters the continent during day 24.

PSP 3 (left panels in Fig. 3) with 14.4 % of the variance shows a long-wave trough on the north-south axis placed over the Pacific Ocean that moves very slowly during the three days. Due to this trough, the semipermanent subtropical anticyclone of the South Pacific Ocean is perturbed 30°S south and remains located to the west of 120°W.

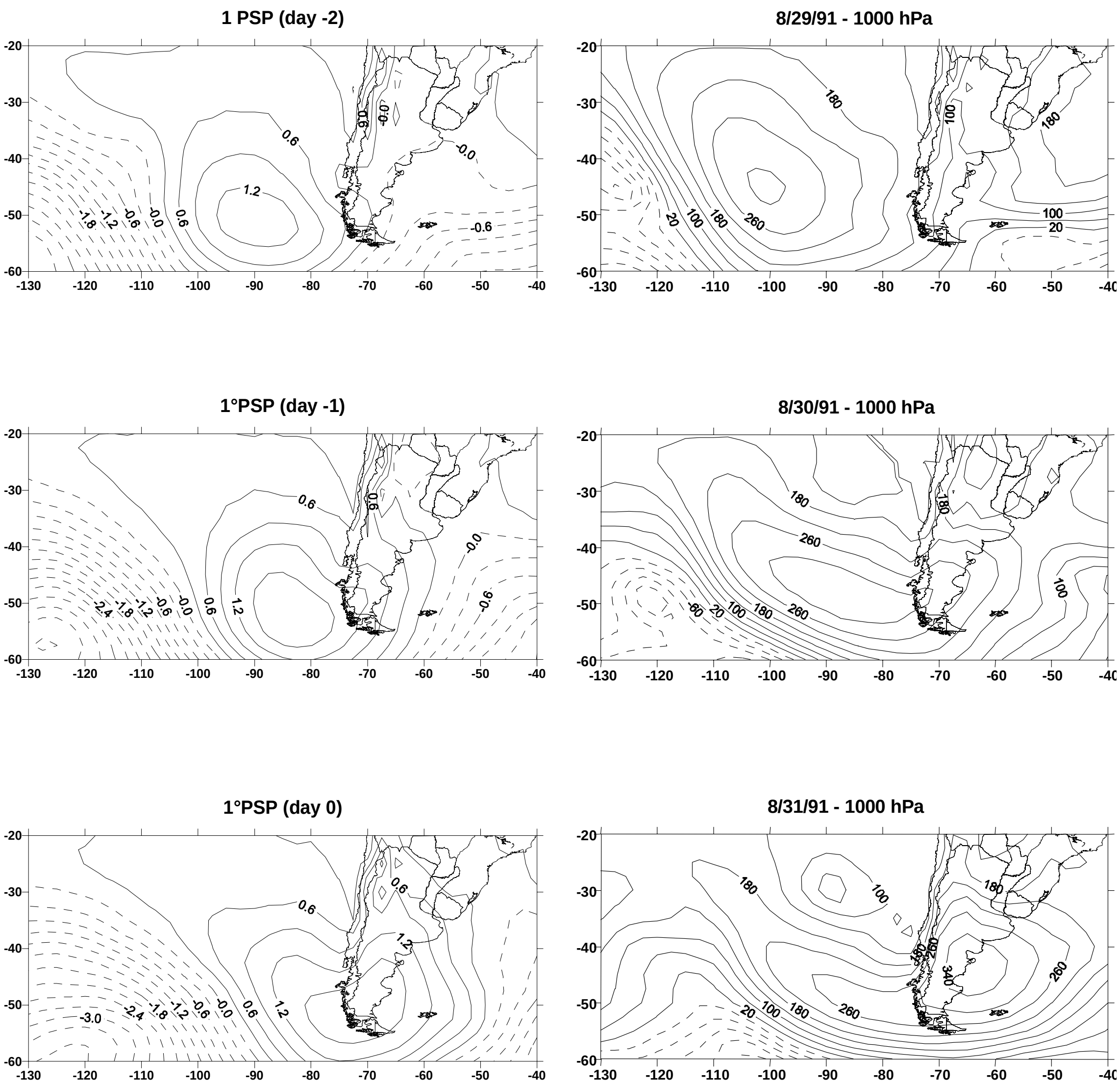

Fig. 1. First main sequence patterns (left) and real sequence of 1000 hPa geopotential height fields for 29-31 August 1991(right).

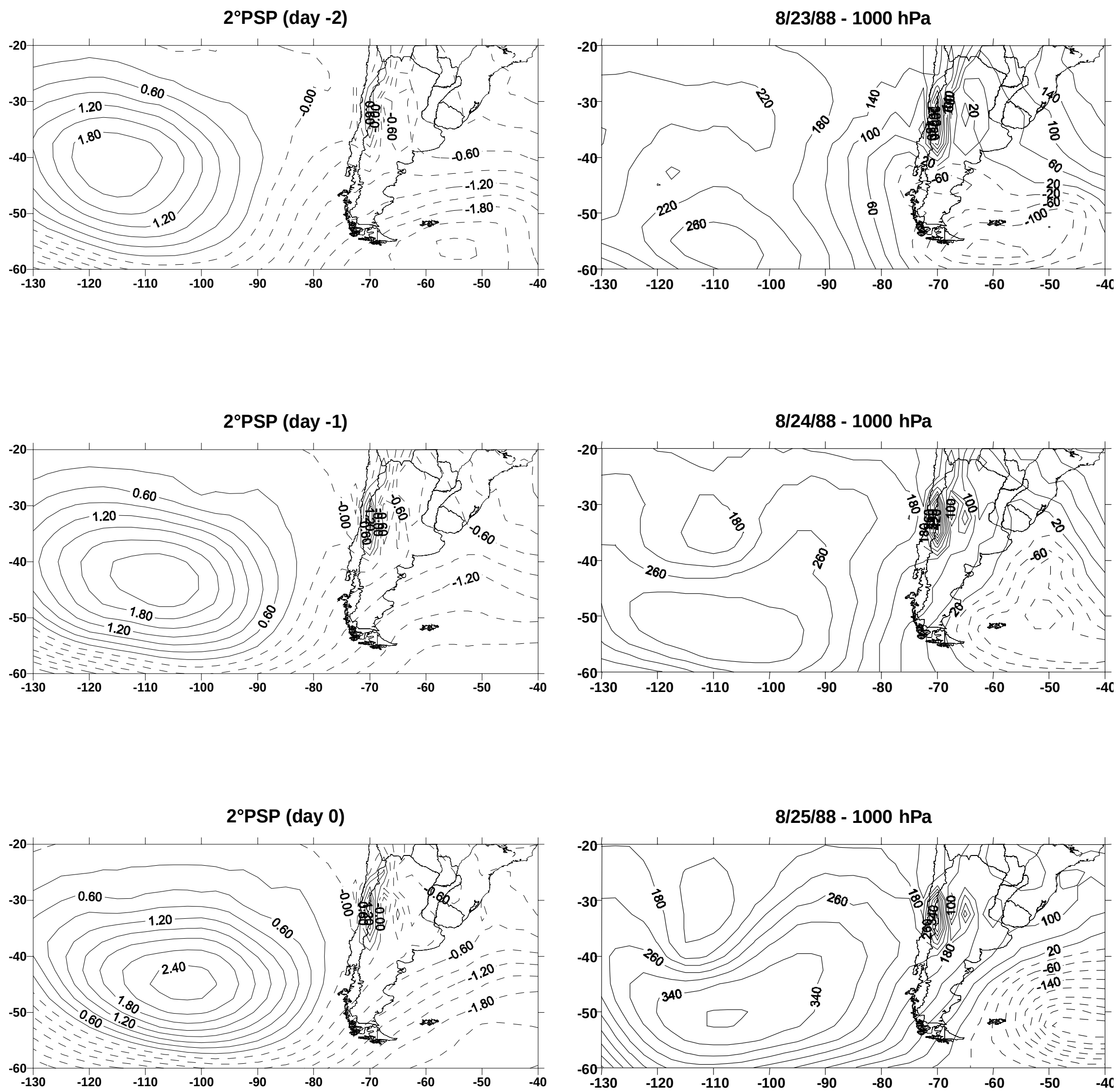

Fig. 2. Second main sequence patterns (left) and real sequence of 1000 hPa geopotential height fields for 23-25 August 1988 (right).

Furthermore, a postfrontal anticyclone begins to enter the continent during day –1 at 40°S. The day the temperature dropped its center is located on the east coast of the continent at 55°S, and covers the central / northeast part of the Southern Cone. The advance and the development of a migratory anticyclone toward the east, associated to the passage of a cold front, can be observed on day –1. This kind of surface pressure configuration contributes to introducing the cold air into low latitudes.

The right panels in Figure 3 show an example of a real situation. The process that begins on 22 July 1993 (top panel) and finishes on 24 July 1993 (bottom panel) causes temperature to drop 5.4°C.

PSP 4 (left panels in Fig. 4) explains 9.4 % of the variance, with a minimum geopotential height centered in 120°W, 35°S that moves slowly during de next days. At the same time, a belt of maximum geopotential height can be observed extended from the south Pacific Ocean (125°W, 55°S) toward the north-east reaching the central part of the continent and connected with the Subtropical Atlantic anticyclone that affects the east coast.

On day –1, the branch of the anticyclone belt located in the eastern part of the Pacific Ocean is developing and affecting the southern part of the continent. Its center is positioned over 80°W, 45°S propagating to the northeast and centered in north Patagonia on day –0. This high system is related to the passage of a cold front that contributes to cold air advection over central Argentina.

A real sequence of surface charts (right panels in Fig. 4) shows the movement of a cold front over Buenos Aires during 12 UTC on 17-19 June 1990. Such situation causes temperature to drop 6.1°C over the city. In addition, a system of low pressure located at 120°W, 40°S can be observed propagating towards the east as the migratory anticyclone enters the continent, which is also observed in PSP 4.

5. Geopotential height at 500 hPa

Complementarily, the 500 hPa level is also analyzed as it represents the middle troposphere and leads to the surface systems that are valued in the weather forecast.

The PSP analysis is again applied to obtain the lead sequence in the middle troposphere. In this case only three PSP explain 70% of the variance, while for 1000 hPa, seven PSP were needed. Therefore, the varimax rotation is applied for the first three PSP in the 500 hPa analysis. The variance and the accumulated variance for the rotated PSP are shown in Table 2.

Figures 5 to 7 show the first three PSP and the actual circulation sequence patterns that have a loading factor greater than 0.7 with each sequence.

As found in the case of 1000 hPa, the inverse mode did not represent significant variances different from zero. That means the inverse mode is not a real situation related to cold outbreak over Central Argentina.

i) PSP 1 (left panels in Fig. 5) explains 25.5 % of the variance, showing a long-wave trough with an axis extending southeastward from subtropical latitudes to the southern part of the continent. At the same time, a high-pressure region associated with intense anticyclone was observed at 120°W, 50°S. This pattern of circulation at upper levels slowly moves eastward with blocking situation in the Southern Hemisphere (Sinclair, 1996).

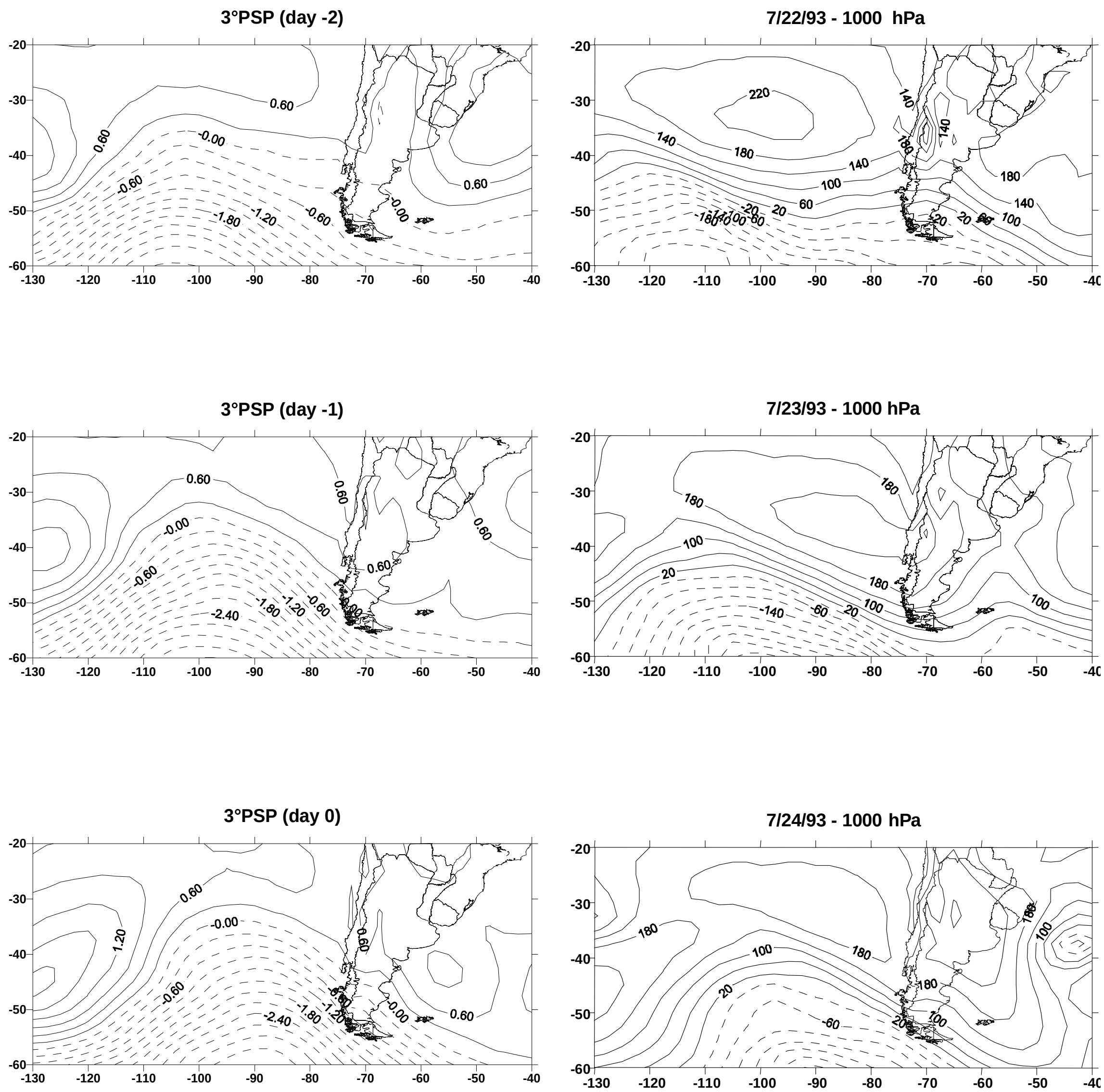

Fig. 3. Third main sequence patterns (left) and real sequence of 1000 hPa geopotential height fields for 22-24 July, 1993.

Table 2. Percentages of variance explained and cumulative percentage explained by the three components.

PSP	VAR.(%)	PER.CUM.VAR. (%)
1°	25.5	25.5
2°	23.8	49.3
3°	21.1	70.4

The real sequence (right panels in Fig. 5) shows a very similar configuration of the circulation; however, the trough in the Pacific Ocean has a more complex structure and behavior than that observed in the PSP. On day –2 (3 May 1984), the axis of the trough evolved in three different sections, one in a lower than 40°S latitude (a: thick line), another in middle latitudes (b: dotted line)**,** and the last one in latitudes south of the continent (c: double line).

Throughout the sequence of the days, axis (c) moves suddenly towards the east and disappears from the analyzed area on day –1; axis (b) moves towards the east and is located to the south of 40°S on day –0 with an inclination of the northwest towards the southeast, this perturbation led the cold surge over Buenos Aires. This part of the trough can be moved eastward, possibly because the mountain range of the Andes is not higher than 2000 meters at those latitudes, while to the north of that latitude the sector of the trough (a) remains in the Pacific Ocean. In brief, the structure in the middle troposphere corresponds to a fast short-wave trough superposed over the long-wave trough that lets the cold air into central Argentina (Krishnamurti *et al*., 1999).

ii) PSP 2 (left panels in Fig. 6) describes 23.8 % of the variance. The pattern describes an important long-wave trough extended over all the South Pacific Ocean southern of 35°S.

At the same time, a big anticyclone is located in all the South Atlantic Ocean with a ridge axis at 55°S. Between both systems, a short wave trough influences the western part of the continent and moves towards the southeast.

The real cases partially agree with this pattern. An example of real situations corresponding to 22 – 24 July 1993 can be seen in the right panels in Figure 6, where the main system, particularly over the Pacific, is represented. Two regions are affected by low pressure systems: a pronounced trough over the Pacific Ocean near 95°W and to the north of 35°S, and a trough over the continent at middle latitude to the south of 40°S.

The second wave at middle latitude is located over the center of the country on day –1 and moves rapidly toward the northeast while intensifying, reaching the south of Brazil on day 0. Such perturbation corresponds to a typical cold surge over the country that causes temperature to drop over Buenos Aires. In addition, an important low pressure zone can be seen over the South Pacific Ocean associated with a long wave trough extending south-eastward and moving slowly for three days.

PSP 3 (left panels in Fig. 7) explains 21.1 % of the variance. The theoretical pattern has a mayor ridge along a north-south axis close to 90°W over the Pacific Ocean and a pronounced trough along a north-west / south-east axis over the Atlantic Ocean near 45°W. On day –2 a high pressure

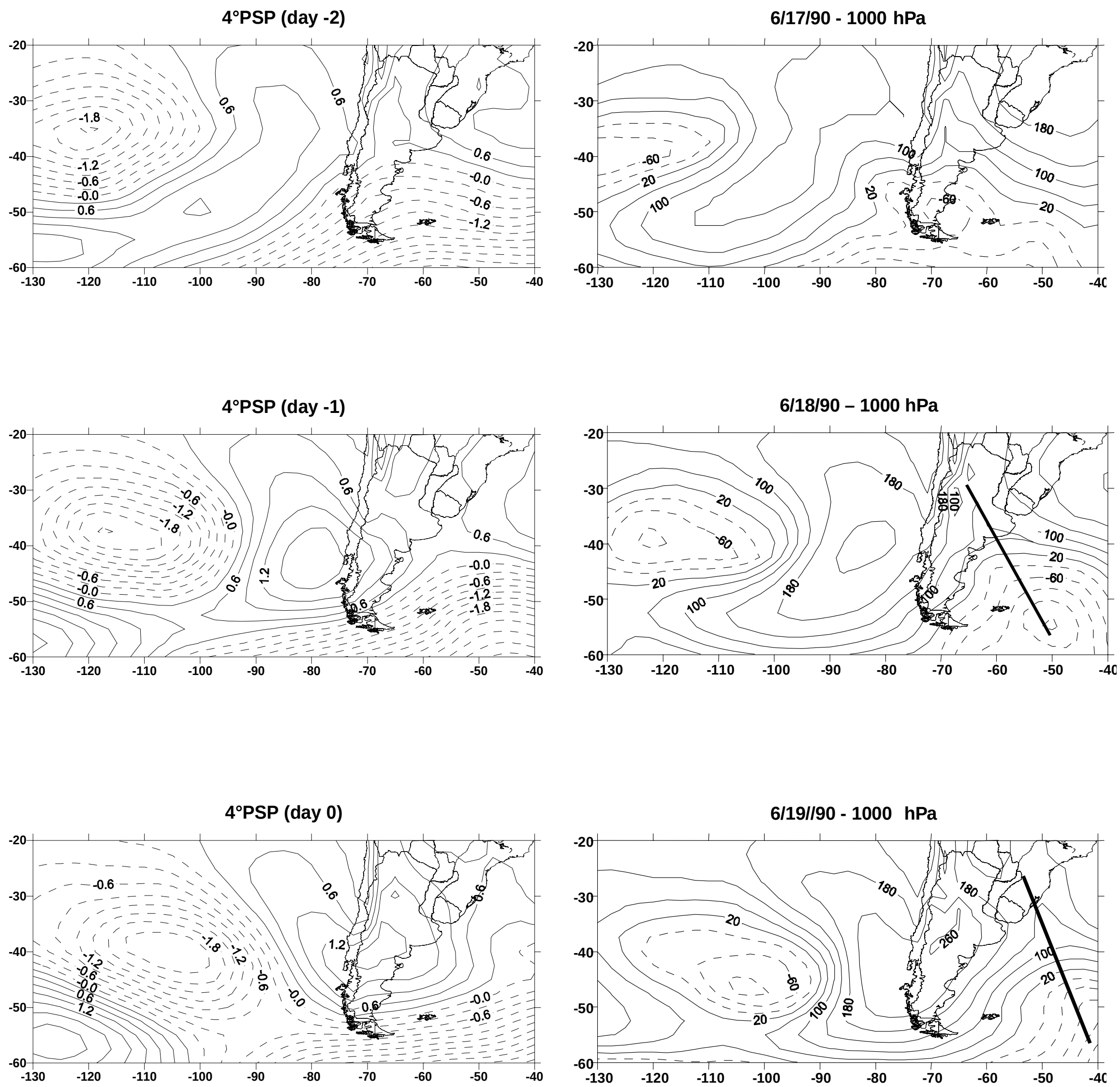

Fig. 4. Fourth main sequence patterns (left) and real sequence of 1000 hPa geopotential height fields for 17-19 June 1990 (right).

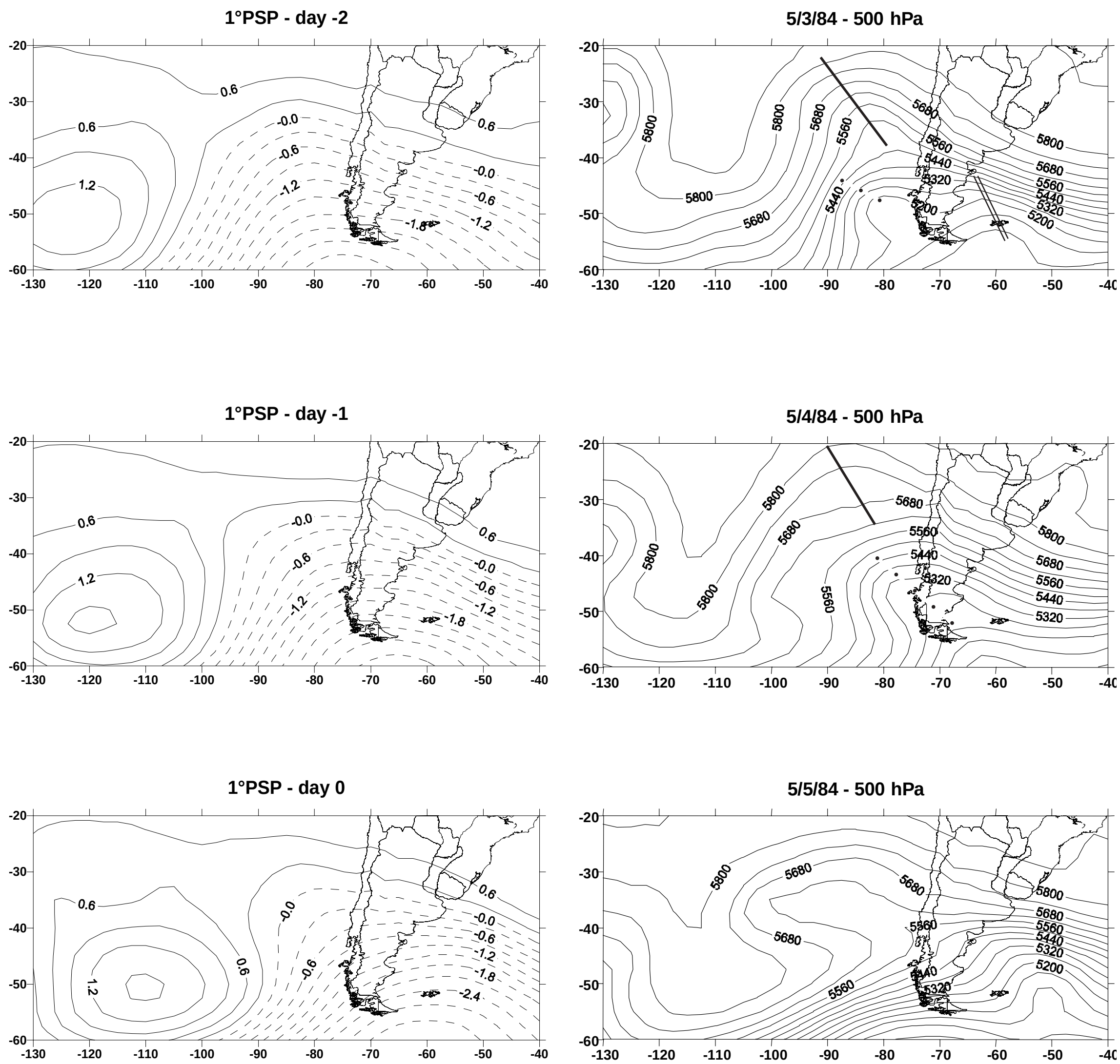

Fig. 5. First main sequence patterns (left) and real sequence of 500 hPa geopotential height fields for 3-5 May, 1984 (right).

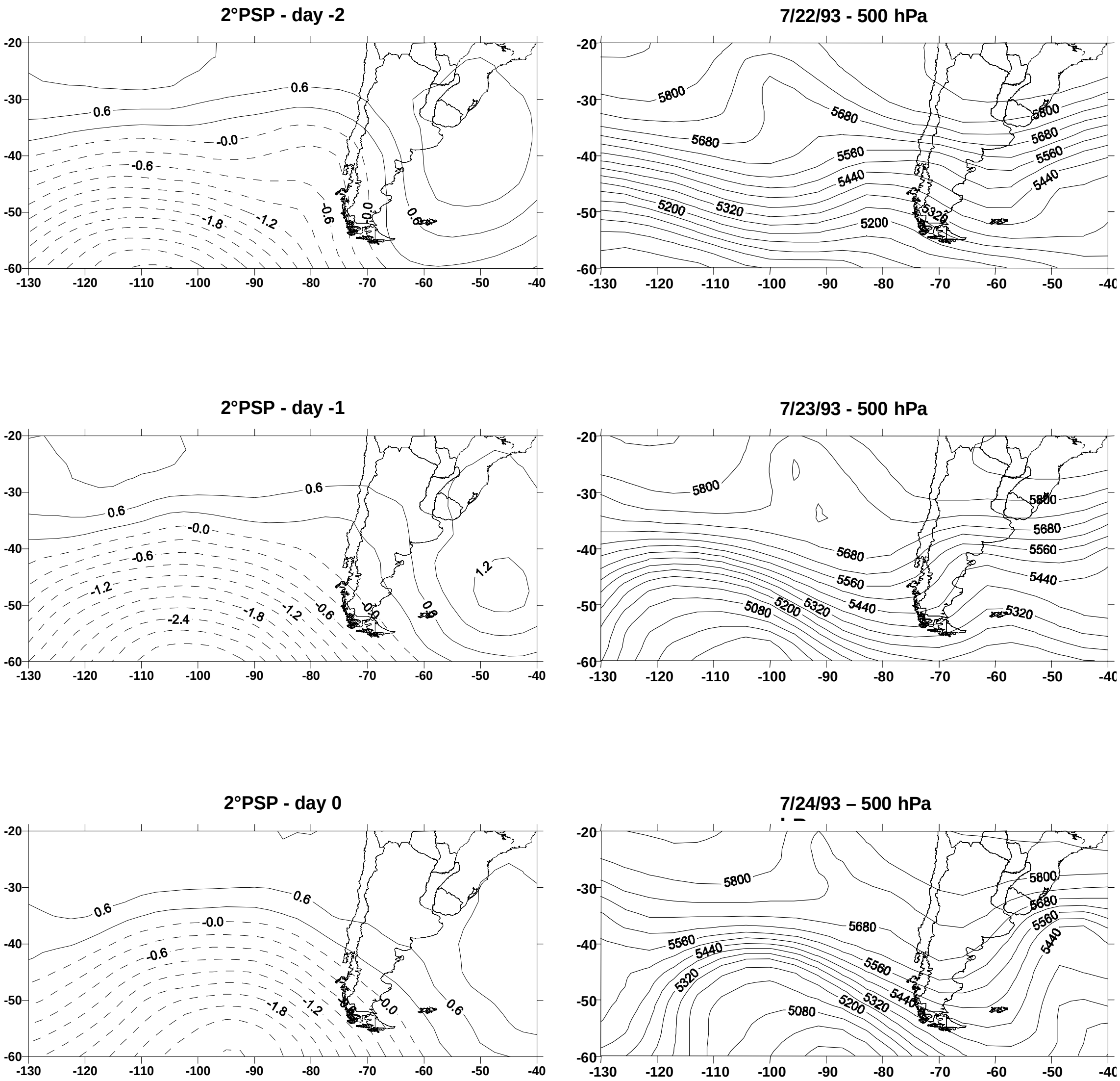

Fig. 6. Second main sequence patterns (left) and real sequence of 500 hPa geopotential height fields for 22-24 July, 1993 (right).

system center can be observed in 95°W, 60°S moving eastward and located on day –0 over the south-east of Chile. At the same time, over the Atlantic Ocean, there is a strong trough along a north-west / south-east axis between days –2 and 0, intensifying as it moves eastward. Such an upper level geopotential heights distribution results in south / south-westerly flow over all of Argentina and lets the cold air at low levels move towards the north of the country. This pattern contributes to notorious descending motions over most of the continental area and corresponds to a typical omega structure related to blocking situations (Elliot and Smith, 1949; Trenberth and Mo, 1985).

The real sequence shows a close similar geopotential heights configuration corresponding to 12 – 14 September 1988 (right panels in Fig. 7). A pair of ridge-trough systems is observed in the Southern Cone, traveling very slowly eastward. During the temporal evolution of the meteorological situations, the deep trough shows a strong confluence of flow from the southwest as shown in the PSP over all of Argentina.

6. Relationships between upper level and low level sequences of circulation patterns

In order to study the vertical structure of the atmospheric circulation associated with cold surges over central Argentina, the fields of geopotential heights at 1000 hPa and 500 hPa were related. The relationships between the low and upper - level patterns were obtained through the analysis of the component loading time series for each of the main components at each level (figures not shown).

Table 3 shows the correlation coefficients between the series of factor loading of 1000 hPa and 500 hPa.

The best relationships between all the possible combinations for both levels were obtained for:

i) PSP 1 at 1000 hPa with PSP 3 at 500 hPa (correlation = 0.71)

Figure 8 shows a pair of daily sequences at 500 hPa (left panels) and 1000 hPa (right panels) on 8 – 10 June 1989 associated with these patterns. Such situation produces a temperature fall of 5.3°C over Buenos Aires. These (500 hPa and 1000 hPa) patterns represent the most frequent situations related to cold surges over Central Argentina (Garreaud, 2000). A north /south ridge over the Pacific Ocean close to the coast of Chile extended into the south of the continent can be observed at the upper level (left panels in Fig. 8). In addition, an anticyclonic center was observed over the south-eastern Pacific related to the ridge, reaching its maximum value on day –0. Furthermore, a trough over the Atlantic Ocean along a northwest/southeast axis moves slowly toward the northeast as it intensified. Such configuration produces a persistent southwesterly flow at the upper level that generates frequent passages of migratory system at the low levels. In those cases, Central and Northern Argentina is dominated by a strong cold air advection that persists for several days. The right panels in Figure 8 show the temporal evolution of meteorological systems at low levels. An anticyclonic perturbation centered on day –2 at around 85°W, 50°S propagating north-eastward and located on day –0 can be observed over Buenos Aires outskirts.

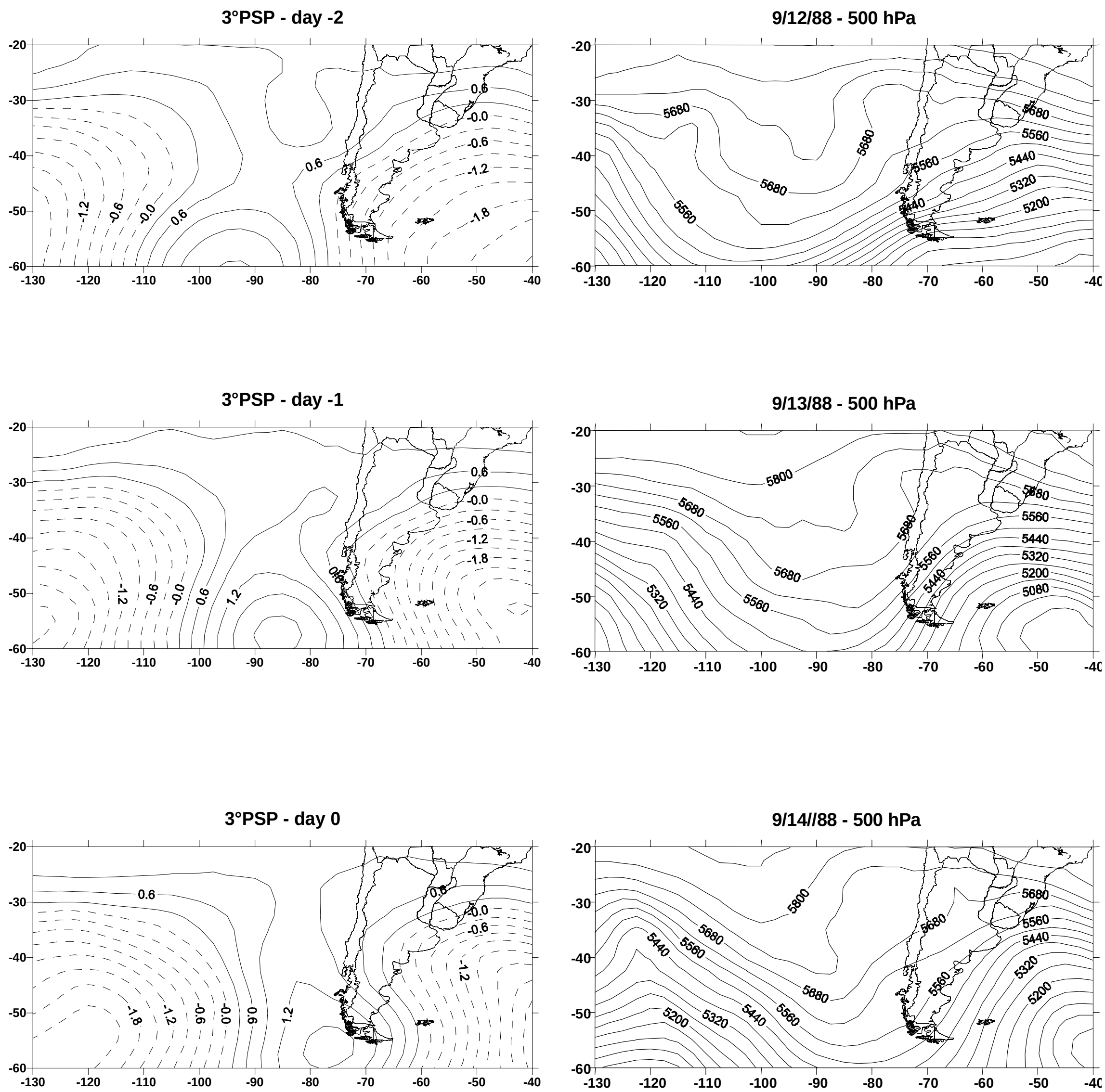

Fig. 7. Third main sequence patterns (left)and real sequence of 500 hPa geopotential height fields for 12-14 September 1988 (right).

Table 3. Correlation coefficients between the series of factor loading of 1000 hPa and 500 hPa.

	PSP500 1	PSP500 2	PSP500 3
PSP1000 1	-0.56	0.10	0.71
PSP1000 2	0.86	-0.58	-0.34
PSP1000 3	-0.49	0.88	-0.41
PSP1000 4	0.40	-0.36	0.12

ii) PSP 2 at 1000 hPa with PSP 1 at 500 hPa (correlation = 0.86)

Figure 9 shows a particular case related to this pair of sequences at the 1000 hPa and the 500 hPa levels. This situation begins on 3 May 1984 and finishes on 5 May 1984, causing a sharp temperature fall of 8.7 °C. The large circulation at the 500 hPa level (the left panels in Fig. 9 are characterised by a long wave with a ridge along a north-south axis over the Pacific Ocean and a strong trough extended from the west of the Andes into the south-western Atlantic Ocean. Such configuration pattern over the Pacific Ocean persists between day –2 and day –0, while a short wave cyclonic perturbation moving eastward and located over Atlantic Ocean is observed over the continent on day –1. The surface pressure configuration (right panels in Fig. 9) shows an intense anticyclonic center located around 110°W, 50°S that moves slowly eastward. At the same time, a low pressure system can be observed over Patagonia on day –1 moving to the east and located at around 50°W, 55°S on day –0. In addition, a migratory anticyclone advances over Central Argentina pushing cold air from the south of the country. This kind of configuration pressure over the whole troposphere characterised by slow propagation is associated with blocking situations over the Pacific Ocean (Sinclair, 1996).

iii) PSP 3 at 1000 hPa with PSP 2 at 500 hPa (correlation = 0.88)

A particular case associated with this pair of sequences is observed in Figure 10. The meteorological situation corresponds to 22-24 July 1993 when the temperature fall was 5.4 °C. At the upper level (left panels in Fig. 10) a long wave trough over the Pacific Ocean along a northwest / southeast axis that exhibits amplification as it moves eastward can be observed. At the same time, there is a wave trough to the west of the Andes on day –2 propagating toward the northeast and located on day –0 over eastern South America. At the low level (right panels in Fig. 10), a post-frontal anticyclone entering the continent was observed on day –1 at around 40°S and located over Central Argentina on day –0. Such evolution of low-level configuration corresponds to the cyclonic perturbation observed at the 500 hPa level. In addition, the wave trough at the 500 hPa level becomes deeper as it begins to move eastward, particularly when it is located over the Atlantic Ocean. The geopotential height at 1000 hPa shows an intense cyclone over the Atlantic Ocean at 35°S, 45°W connected to the high level perturbation described above. This low-level pressure system also contributes to push the cold air mass from the south toward the lower latitudes.

PSP 4 is not directly related to a specific condition at 500 hPa, but presents diversity in the conditions of the middle troposphere. This fact becomes evident because of the significantly low correlation value between the component loading time series at 1000 hPa and 500 hPa (Table 3).

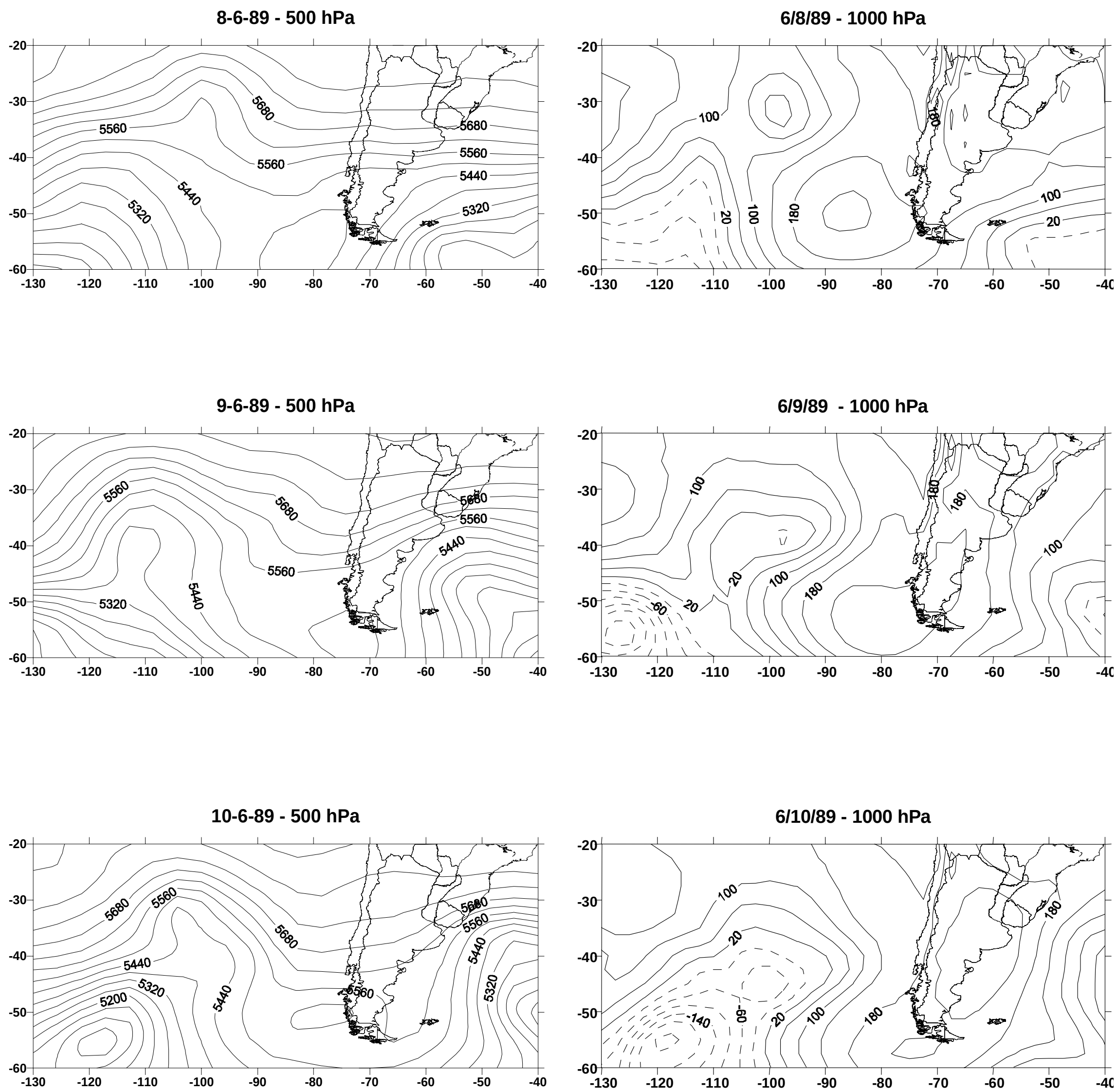

Fig. 8. Real sequences of 500 hPa geopotential height fields (left) and 1000 hPa geopotential height fields for 8-10 June, 1989 (right).

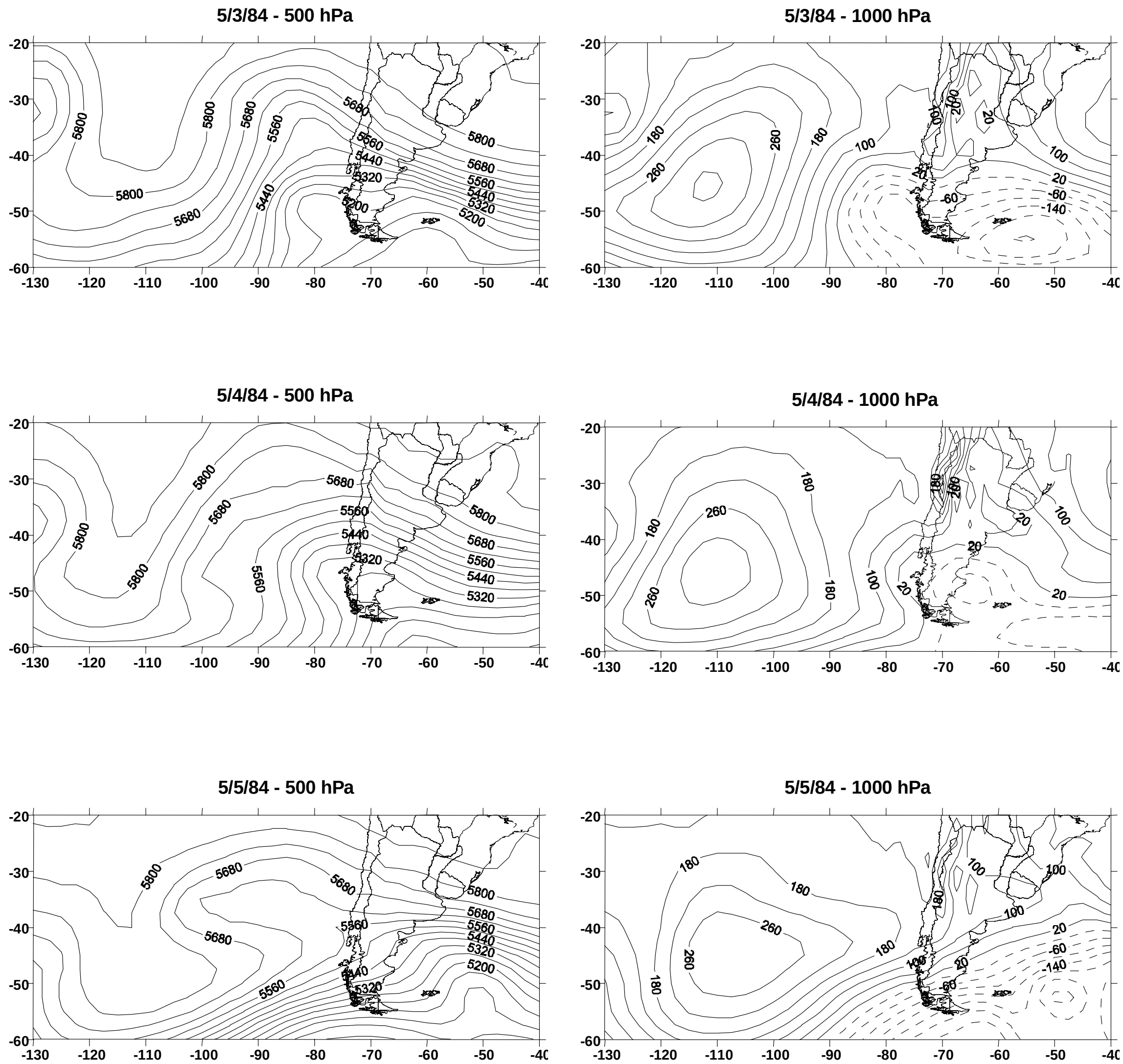

Fig. 9. Real sequences of 500 hPa geopotential height fields (left) and 1000 hPa geopotential height fields for 3-5 May 1984 (right).

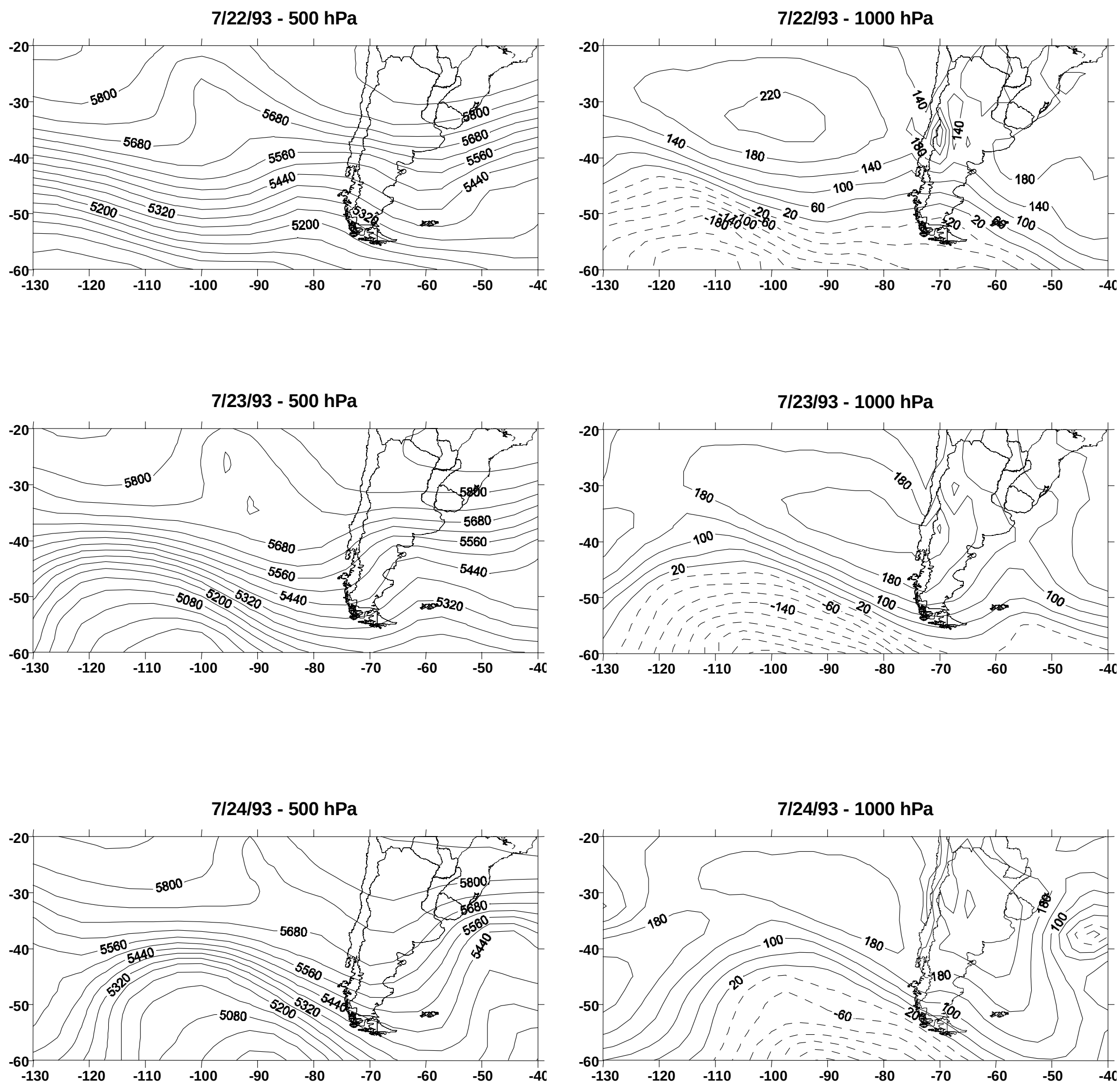

Fig. 10. Real sequences of 500 hPa geopotential height fields (left) and 1000 hPa geopotential height fields for 22-24 July 1993 (right).

7. Conclusions

Since the same percentage of variance (70 %) is explained by PSP 7 at 1000 hPa and only by PSP 3 at 500 hPa, the circulation structures are more variable at 1000 hPa than in the middle troposphere for the case of cold surges over central Argentina.

In the surface, the pattern that leads to cold outbreaks over Central Argentina corresponds to several types of postfrontal anticyclones, the most important associated with polar cold air advection (PSP 1).

At the upper levels, the patterns correspond to a long wave trough affecting the continent on which disturbances of shorter waves are superposed, especially the troughs that move rapidly over Central Argentina. These geopotential height configurations can be seen in the first and second patterns. The long wave trough is much more evident over the continent in PSP 1 than in PSP 2.

The third upper level pattern corresponds to the classic situation analyzed by diverse authors (Garreaud, 2000) and shows an important ridge to the west of the Pacific Coast.

The combination of both levels shows three typical situations related to cold surges over Central Argentina. Two of them correspond to a long wave trough at the upper levels affecting the continent, one with the anticyclone moving over middle and low latitudes (Fig. 9), determined by the PSP 1 at 500 hPa and PSP 2 at 1000 hPa, and the other with the surface anticyclone affecting lower latitudes over the continent (Fig. 10), determined by the PSP 2 at 500 hPa and PSP 3 at 1000 hPa.

Finally, the most classic pattern corresponds to an important ridge to the west of the Pacific Coast that produces descending motions over Central Argentina accompanied by a postfrontal anticyclone in low levels that advects cold air from the south (Fig. 8). The PSP 1 at 1000 hPa and PSP 3 determined this kind of pattern at 500 hPa.

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