Proceedings of 8 ICSHMO, Foz do Iguaçu, Brazil, April 24-28, 2006, INPE, p. 1439-1452.

ATMOSPHERIC CONDITIONS DURING WET AND DRY SUMMER EXTREMES IN CENTRAL-WEST ARGENTINA

Eduardo Agosta * and Rosa Compagnucci

Department of Atmospheric and Oceanic Sciences, School of Sciences, University of Buenos Aires
The Argentine Council of Sciences and Technique Research (CONICET

Abstract: The summer (Oct-Mar) rainfall in Central-West Argentina (CWA) shows a clear interannual variability modulated by low-frequency oscillations. This determines periods of wet and dry summers that have changed from a quasi-18-year cycle towards lower frequencies in the summer 1976/77 (Compagnucci et al. 2002). The relationship between dry and wet extremes and the atmospheric circulation is analyzed regarding the era pre-1977 and pos-1977. Extreme events were defined using the first and third quartile of the distribution of a summer precipitation index devised for the region. The composite shows differential features between dry and wet extremes and in relation with the change in 1976/777.
These results suggest a possible change in the teleconnection between summer rainfall and the atmospheric circulation, from middle to subtropical latitudes by mid-1970s.

1. INTRODUCTION

According to Compagnucci et al. (2002, CAV02 hereafter), the October-to-March precipitation in Central-West Argentina (CWA, Fig. 1) shows a clear interannual variability modulated by low-frequency oscillations. The main significant interdecadal oscillation is the cuasi-18-year cycle that apparently has shifted towards lower frequencies in the austral summer 1976/77. Until the mid-1970s, the former cuasi-cycle determined alternating periods of wet/dry summers of roughly 9 years of duration each. The start of the last 9-year wet period is 1973 and the wet signal prolonged during the 80s and 90s with few interruptions, recording in 30 years, 20 wet summers. The prolonged wet period has given rise to an increment of 20% in the regional average.

* *Corresponding author address:* Eduardo A. Agosta, Departamento de Ciencias de la Atmósfera y los Océanos, Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires. Pabellón II, 2do piso, Ciudad Universitaria CP 1428, Buenos Aires, Argentina; e-mail: agosta@at.fcen.uba.ar

Partly, the shift in the precipitation variability is adjudicated to the climate transition observed in the summer 1976/77 (CAV02). The transition undergone by the climate system meant a shift towards warming in the mean conditions of the sea surface temperatures in the equatorial central Pacific (Huang et al. 2005) whose effects on climate were soon noted after the event (Namias 1978) but the true climatic significance in nature and consequence was just understood in the 1990s (Ebbesmeyer et al. 1991, Trenberth 1995, Zhang et al. 1997, Mantual et al. 1997, Garreaud and Battisti 1999).

Therefore, our objective is to determine the differential features of the atmospheric circulation between the extreme wet summers and the extreme dry summers in CWA and wether the climate transition of the austral summer 1976/77 influences upon them.

2. DATA AND METHODOLOGY

Information of the atmospheric circulation is obtained using 2.5° grid monthly data from the NCEP/NCAR reanalysis I (www.cdc.noaa.gov). The variables analyzed are geopotential height (HGT, mgp) at 850, 500 and 200 hPa, vector wind (m/s) at 850 hPa and specific humidity (Q, g/kg) at 850 hPa.

Regional precipitation data consist of monthly precipitation totals from 9 meteorological stations within the CWA (see Table 1) from the ´Servicio Meteorológico Nacional´ (Argentine Weather Service). The information is used to estimate the regional index ***P(t),*** devised by Agosta et al. (1999), that captures the inter-annual to multidecadal variability of summer precipitation in CWA. Also monthly 0.5° latitude-longitude grid interpolated data of observed precipitation from the University of Delaware (UDel) is used to examine precipitation fields within Argentina.

The index ***P(t)*** is estimated as the percentage ratio between total (Oct-Mar) summer precipitation at each station and the station mean, averaged on all the stations following the formula:

$$Y_j(t) = (X_j(t) \cdot 100) / \chi_j \qquad 1 \leq j \leq n$$

$$P(t) = \sum_{j=1}^{n} Y_j(t) / n$$

where,

Y_j (t): summer rainfall single series of station j, expressed as percentage of its 1958-1998 long run average.

X_j (t) : station *j´s* summer precipitation in year *t*.

j. index of stations,

n: number of station (n=9 for the study).

Positive (negative) values of the index anomaly denote wet (dry) summers. The index was recalculated for the period 1958-2004 on the baseline 1959-1998 (the year indicates the end of the season). We decided to use only data from 1958 because the monthly atmospheric data from NCEP-NCAR reanalysis used to examine the atmospheric circulation are more confident since 1958 over the SH (Kistler et al. 2001). Besides, some authors suggest that there may be a reversal trends in the South America precipitation series in 1998 due to possible reversal in the Pacific basin low-frequency variability (Huang et al. 2005). This could also be inferred to the CWA precipitation since from the summer 2001 there seems to be a negative trend, though the short record cannot allow us to evaluate this inference (Fig. 2).

The criterion to determine extreme summers is of the first quartile (k1=-19.7%) and the third quartile (k3=+18.46%) for the distribution of the index anomaly in the period 1959-1998. The extreme years used for the composition of summer fields are shown in Table 2.

We analyze the atmospheric circulation anomalies for CWA precipitation extremes relative to the climate transition 1976/77 dividing the whole period into 1958/59-1976/77 and 1978/79-1997/98. The composition of summer field anomalies are statistically tested respect each period using the t-Student´s test for means and the F-Fisher´s test for standard deviations. The significant level (α) used are always lower than 0.10.

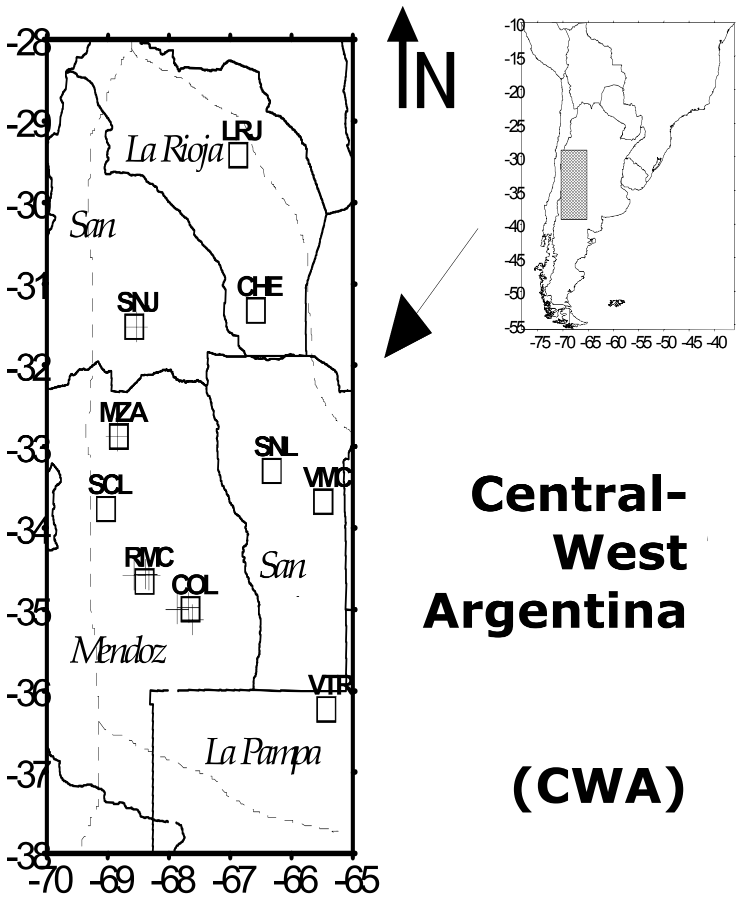

Figure 1: Location of the meteorological stations in the Central-West Argentina (29°-36°S and 65°-70°W) and main Provinces.

Station	**height (m)**	**Latitude (ºS)**	**Longitude (ºO)**	**Record**
(1) La Rioja	516	29º25`	66º52`	1958-2004
(2) San Juan	634	31º32`	68º34`	1958-2004
(3) Mendoza	769	32º53`	68º49`	1958-2004
(4) San Luis	734	33º18`	66º19`	1958-2004
(5)Villa Mercedes	514	33º41`	65º29`	1958-2004
(6) San Carlos	940	33º46`	69º02`	1958-1979
(7) Rama Caída	713	34º40`	68º24`	1958-2004
(8) Colonia Alvear	465	35º00`	67º39`	1958-1979
(9) Victorica	312	36º14`	65º26`	1958-2004

Table 1: Meteorological stations used within CWA**.**

Summer	**Dry extreme, ΔP(t) < k1**	**Summer**	**Wet extreme, ΔP(t) > k3**
1961	-20.2	1960	+25.3
1966	-28.6	1963	+25.1
1967	-30.9	1973	+25.1
1969	-27.6	1974	+33.7
1971	-46.1	1975	+23.7
1972	-38.3	1978	+28.0
1976	-25.0	1979	+38.1
1989	-30.8	1984	+34.8
1994	-33.8	1991	+19.6
1996	-26.6	1992	+18.5
		1998	+22.7

Table 2: Summer extremes dry and wet according to the quartile criterion, k1=-19.7% and k3=+18.5%. ΔP(t): percentage precipitation index anomaly. (The year indicated is of the end of the summer).

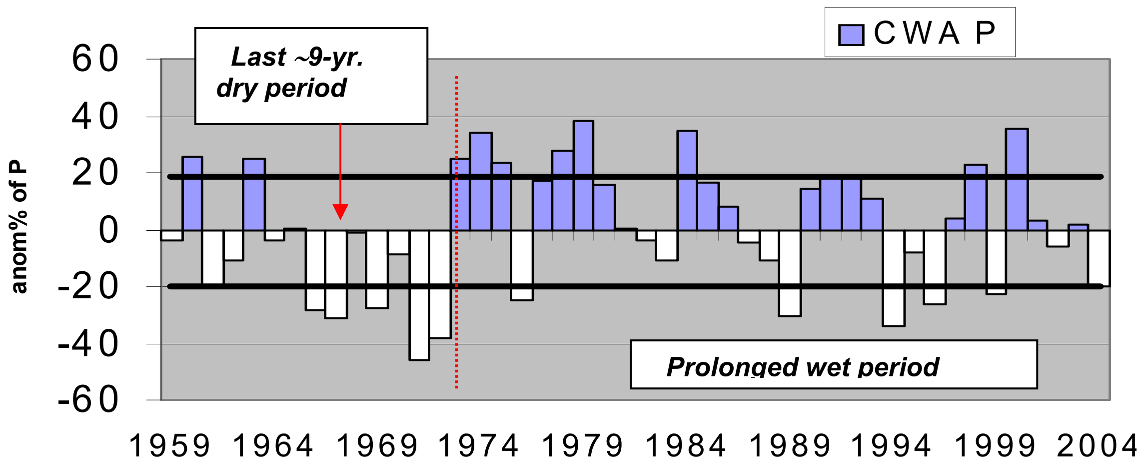

Figure 2: Percentage anomaly of the CWA precipitation index ***P*** estimated from 9 meteorological stations. Horizontal lines: first quartile q_1= -19.7% and third quartile q_3= +18.5%.

3. RESULTS

3.1 Extreme summers in the period 1958/59-1976/77

The intra-regional distribution of percentage precipitation anomaly for the composition of extreme dry and wet summers is shown in Figure 3. Left panels (a.1 and b.1) shows the composite anomalies in CWA from the meteorological station used to estimate the index ***P(t)***, for extreme wets (Fig. 2.a.1) and extreme dries (Fig. 2.b.1). Right panels are analogue (a.2 and b.2), though they are estimated from monthly precipitation of the UDel dataset to extend the figures beyond the region CWA. By comparing both data sets, the minima differences in intensity and form of the spatial structure in the CWA can be due to the different methods of interpolation used and the number of available station at the moment of calculus of each data set. The signals are consistent in sign and spatial structure, although those of the UDel dataset show slightly lower intensity. This allows us to compare the precipitation in CWA with other surrounding areas.

The field of composite anomalies of the percentage precipitation for extreme wets is characterized by a precipitation gradient with maximum (>40%) towards the west-southwest of the CWA (Fig. 3.a.1). The northeast of CWA shows negative values, opposing to the rest. The field from the UDel dataset shows that the positive signal amplifies to the north of the Patagonia, indicating a larger extension of the regional spatial coherence. Another strong signal appears in southern Patagonia (>50%) and strong negative values in central Patagonia (<-60%). Slightly negative anomalies of precipitation (between -10% and 0%) predominate over the rest of subtropical Argentina. It is noteworthy that in the Northwest of Argentina (NWA) there exists another positive center of anomaly.

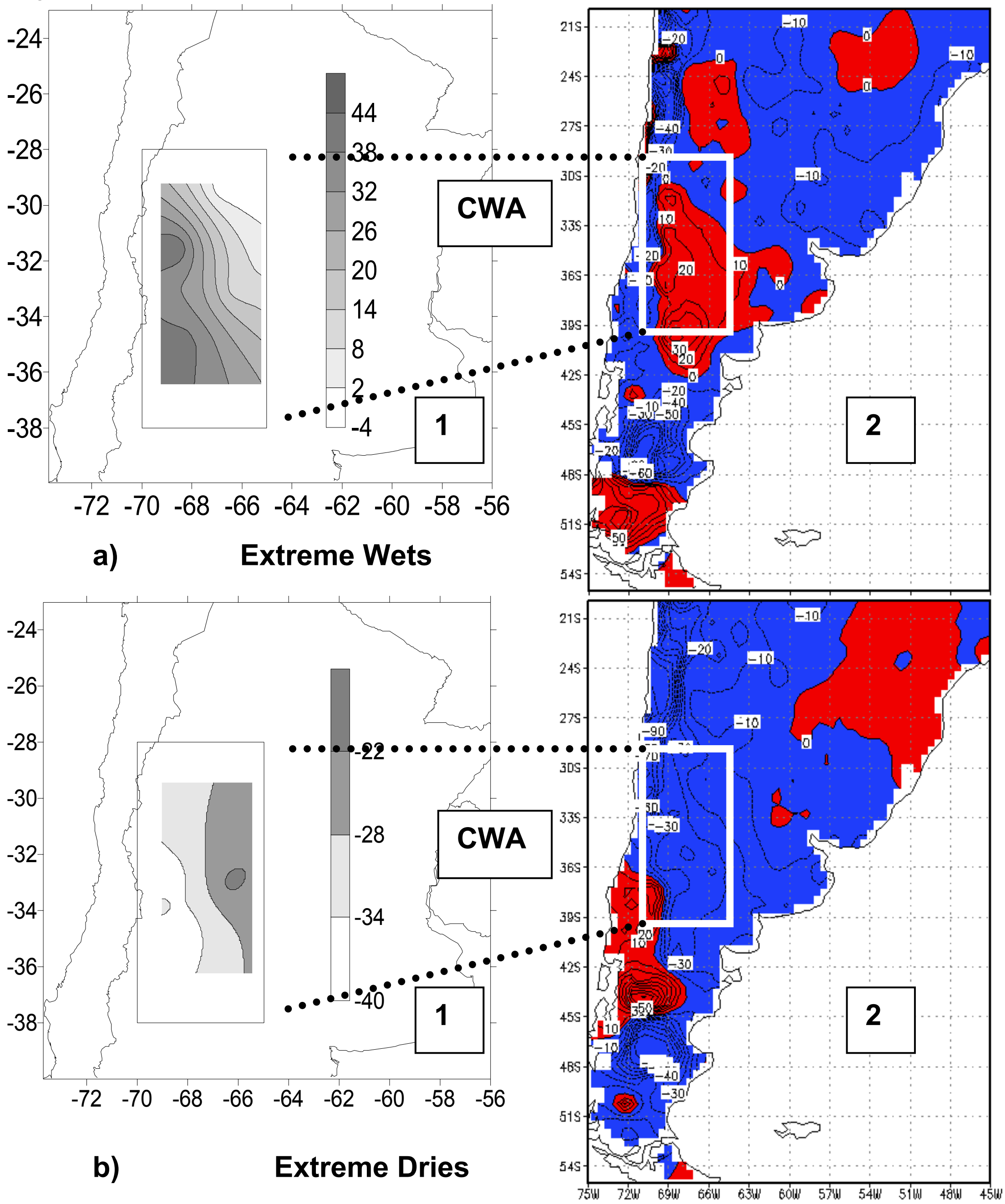

Figure 3: Summer precipitation composite anomaly as percentage from the average on the period 1958/59-1997/98 at each station of the CWA (left panel: 1), or at every grid interpolated point from the Delaware University dataset (right panel: 2) for extreme wet summers (upper panel: a) and for extreme dry summers (lower panel: b) for the period 1958/59-1976/77 (pre-1977).

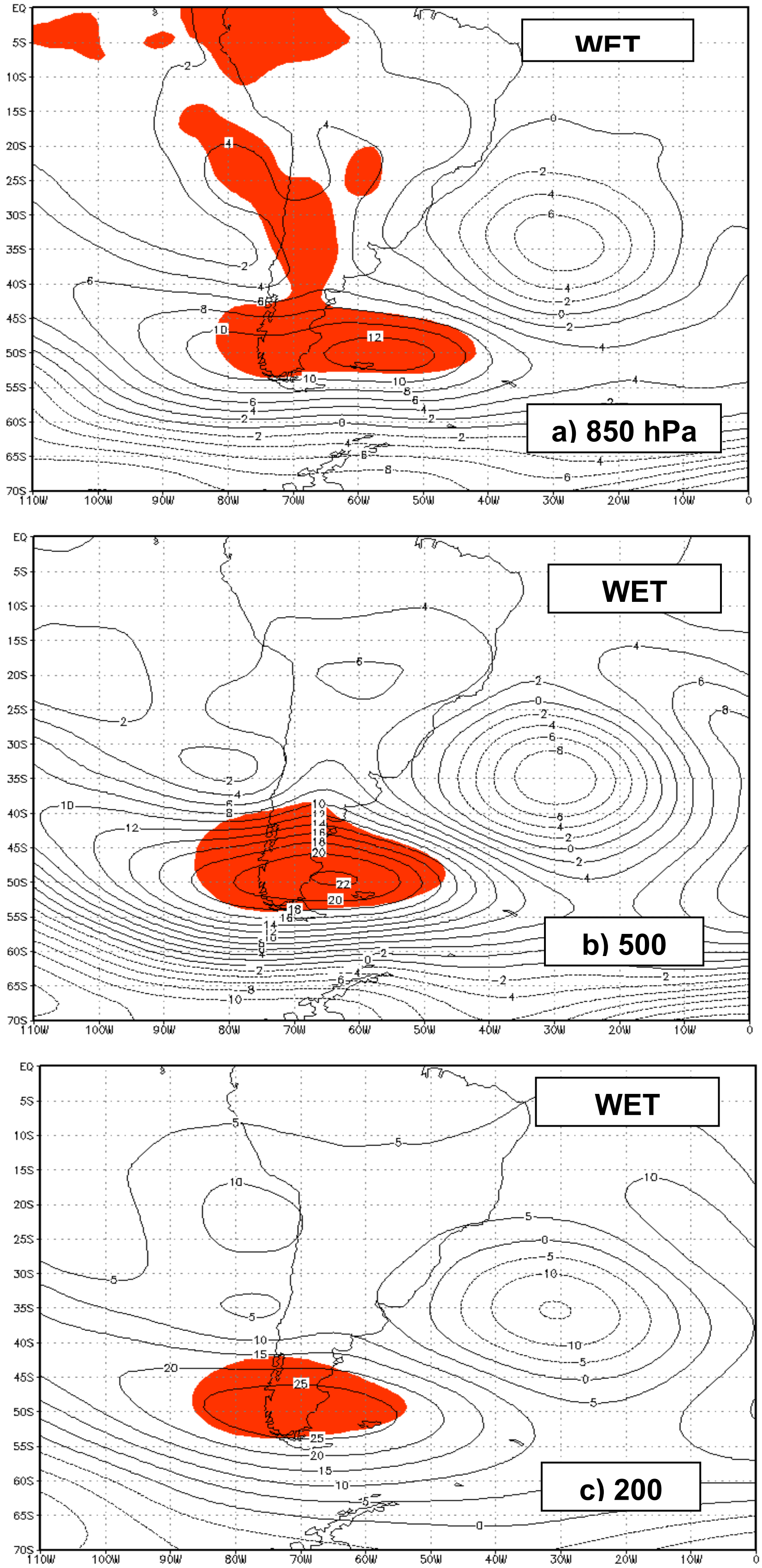

Figure 4: Composite anomalies of geopotential height (mgp) at 850 hPa (a), 500 hPa (b) and 200 hPa (c) for extreme wet summers in the period pre-1976/77. Shaded: significance level $\alpha<0.10$ (Student´s t-test).

The composite anomalies of geopotential height for extreme wets show anticyclonic anomalies from lower to upper levels (Fig. 4.a, .b and .c) over mid-latitudes, indicating a diminution of the westerlies, and thus, of the cyclonic activity. Negative values of composite anomalies over the subtropical South Atlantic reveal a weakening of the South Atlantic Anticyclone (SAA) whereas the positive values over the South Pacific indicate strengthening of the South Pacific Anticyclone (SPA) in lower troposphere. Similar configuration of anomalies appears in the middle and upper troposphere producing a short subtropical wave that favors mean conditions of differential cyclonic vorticity advection (trough) above CWA and the consequent upward motion. The three-dimension configuration of the composite anomalies in mid-latitudes indicates the presence of baroclinic waves due to the westward inclination of the centers with height and the amplification of the signals.

The composite anomalies of specific humidity at 850 hPa (lower troposphere) are consistent with the raise in precipitation, showing the highest positive values in CWA (Fig. 5). The moisture anomaly is associated with a mass flux anomaly from the East-Southeast; which may indicate moisture advection from the South Atlantic, south of 30°S. The raise in humidity is also observed in northern Patagonia and the northwestern of Argentina, while the rest of subtropical Argentina remains with neutral conditions of humidity.

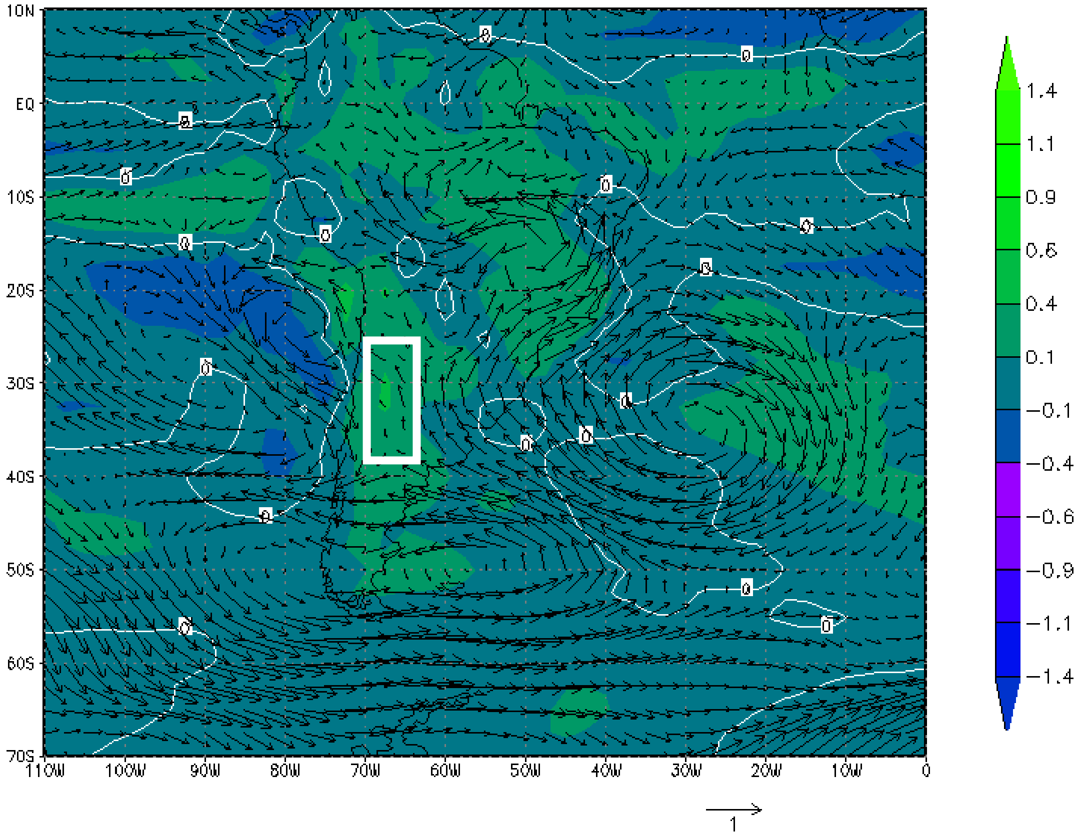

Figure 5: Composite anomalies of specific humidity (g/kg; shaded) and vector wind (m/s) at 850 hPa for extreme wet summers in the period pre-1976/77. Rectangle: location of CWA.

The field of composite anomalies of the percentage precipitation for extreme dries is characterized by an east-west gradient manifested in both datasets (Fig. 3.b1 and b.2), with more intense negative anomalies towards the west (<-20%). From the UDel dataset (Fig. 3.b.2) it is observed that immediately to the south of the CWA, the signal changes the sign (>+50%) in northern Andean Patagonia. Central Patagonia presents a strong negative signal that extends southwards. Negative anomalies predominate in the rest of subtropical Argentina.

The composite anomalies of geopotential height for extreme dries show an inverse spatial structure (Fig 6.a, .b and .c). The negative composite anomalies in lower troposphere over the mid-latitudes means increased cyclonic activity. The light positive values over the subtropical oceanic areas indicate that both the SSA and the SPA seem to be slightly intensified. In mid and upper

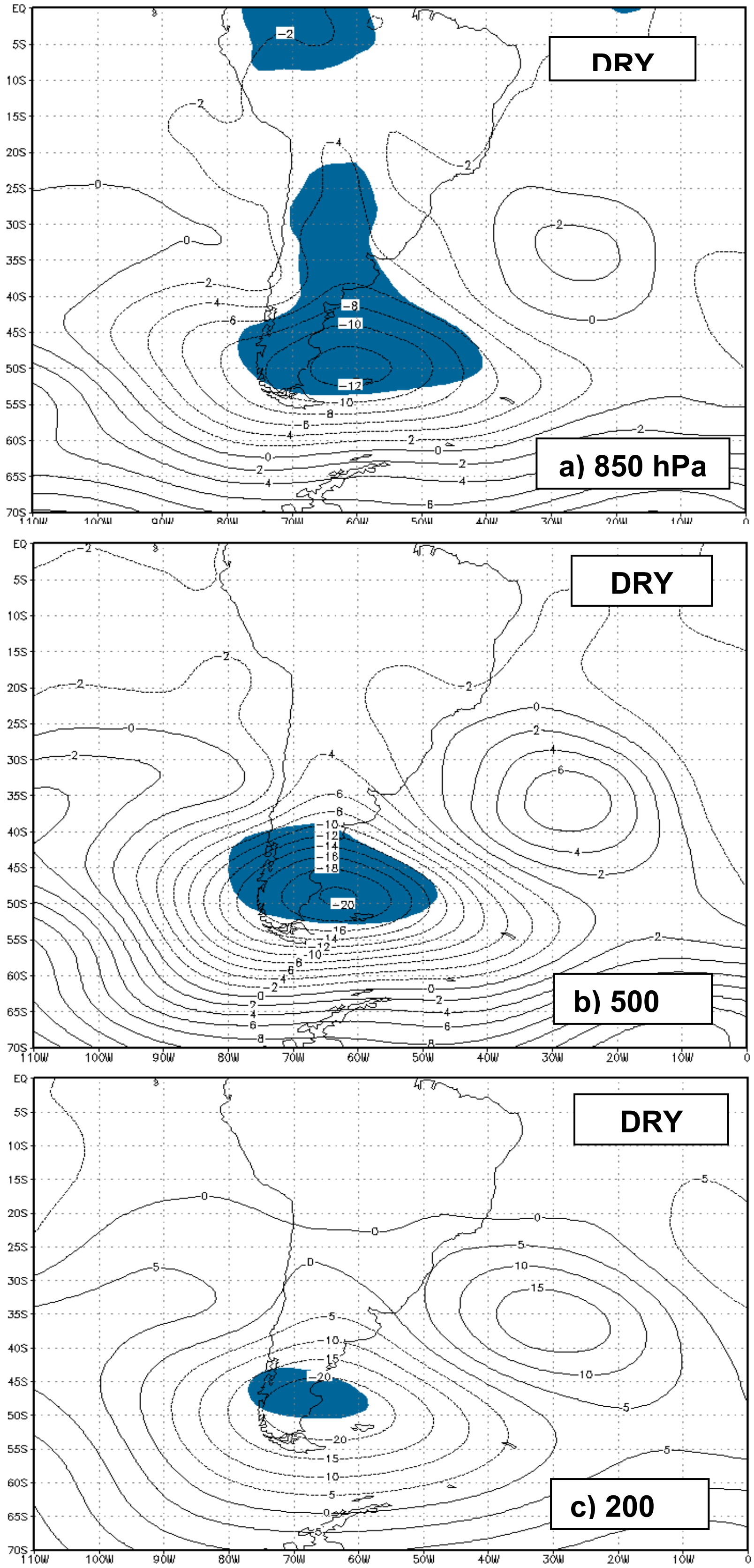

Figure 6: Ídem Figure 4, but for extreme dry summers in the period pre-1977.

troposphere a short subtropical wave produce mean conditions of differential anticyclonic vorticity advection (ridge) over CWA that favors downward motion. As for extreme wets, the three-dimension configuration reveals the presence of baroclinic waves.

The composite anomalies of specific humidity in lower troposphere show lowest negative values over the CWA, extending the signal toward lower latitudes along the east of the Andes (Fig. 7). The negative moisture values can be associated with the mass flow anomaly from the West-Southwest over northern Patagonia, the CWA and central-east Argentina. The air masses transported from the Pacific crossing the Andes south of 40°S, in northern Patagonia, may lose their humidity in the mountains and get dried adiabatically. Also, this would give rise to the bipolar pattern north/wet and south/dry observed over the Andean Patagonia. In turn, the north-northeasterly component of the mass flux anomaly in northeastern Argentina and southern Brazil is associated with the positive values of specific humidity anomaly in the area, which is consistent with the positive values of precipitation in there (Fig. 3.b.2).

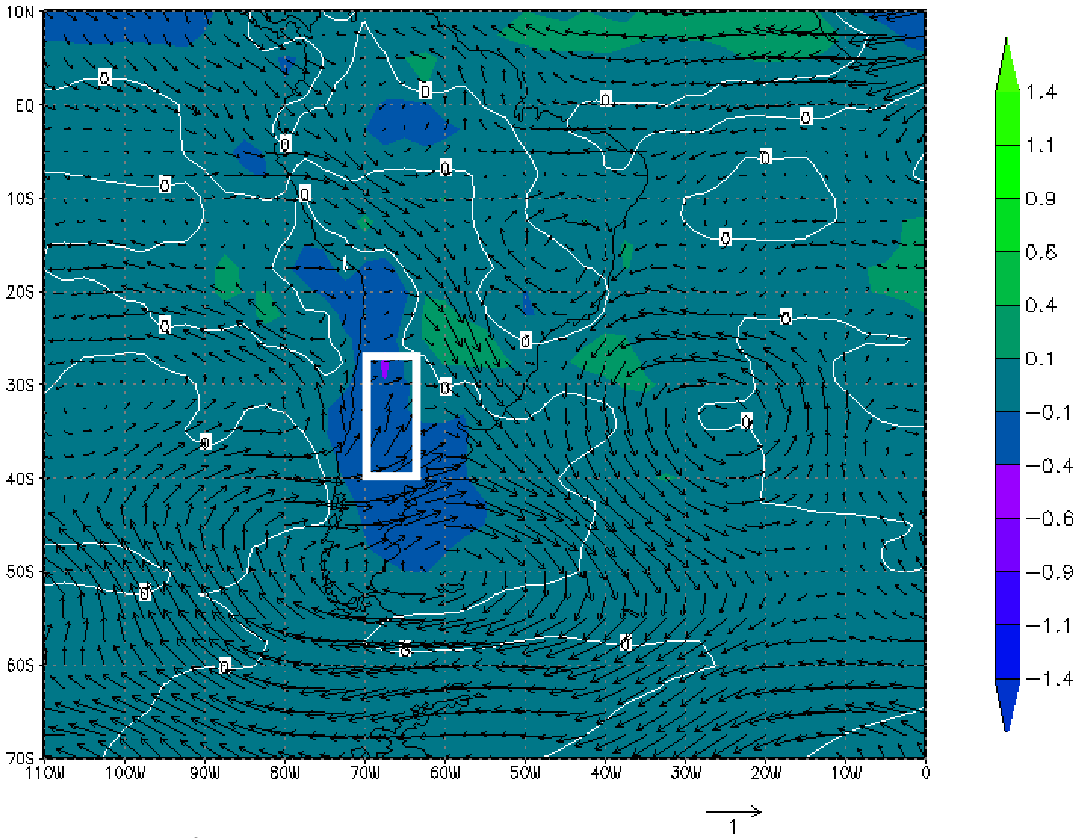

Figure 7: Idem Figure 5, but for extreme dry summers in the period pre-1977.

3.1 Extreme summers in the period 1977/78-1997/98

Figure 8 is similar to Figure 3, but it is for the extreme summers in the period pos-1976/77. The spatial distribution of percentage-precipitation anomalies given by the meteorological station in CWA (Fig. 8.a.1 and b.1) and by the Udel (Fig. 8.a.2 and b.2) differ in intensity and form further than for the period 1958/59-1976/77. However, the sign of the anomalies and the spatial distribution are consistent. This permits to compare the precipitation field in CWA with other areas of Argentina.

The field of composite anomalies of the percentage precipitation for extreme wets shows positive values over the whole CWA, with the highest rates (>+42%) over southwestern CWA and the lower rates in (<+10%) in the centre of the region. The main difference in comparison to the previous period is the percentage raise of the anomaly in the northeast of CWA, which passes from negative to strong positive values, and the relative minimum in the centre due to a reduction in the precipitation in the San Juan station (Agosta et al. 1999). From the Udel dataset, it is observed that values over northern Patagonia are negative (up to -20%), whereas in the previous period the signal was positive in coherence with CWA. Also the pattern of anomalies changes for the rest of Patagonia. A relevant change is the extension of the positive signal of CWA toward the rest of subtropical Argentina, north of 40°S, where the signal was the inverse in the previous period.

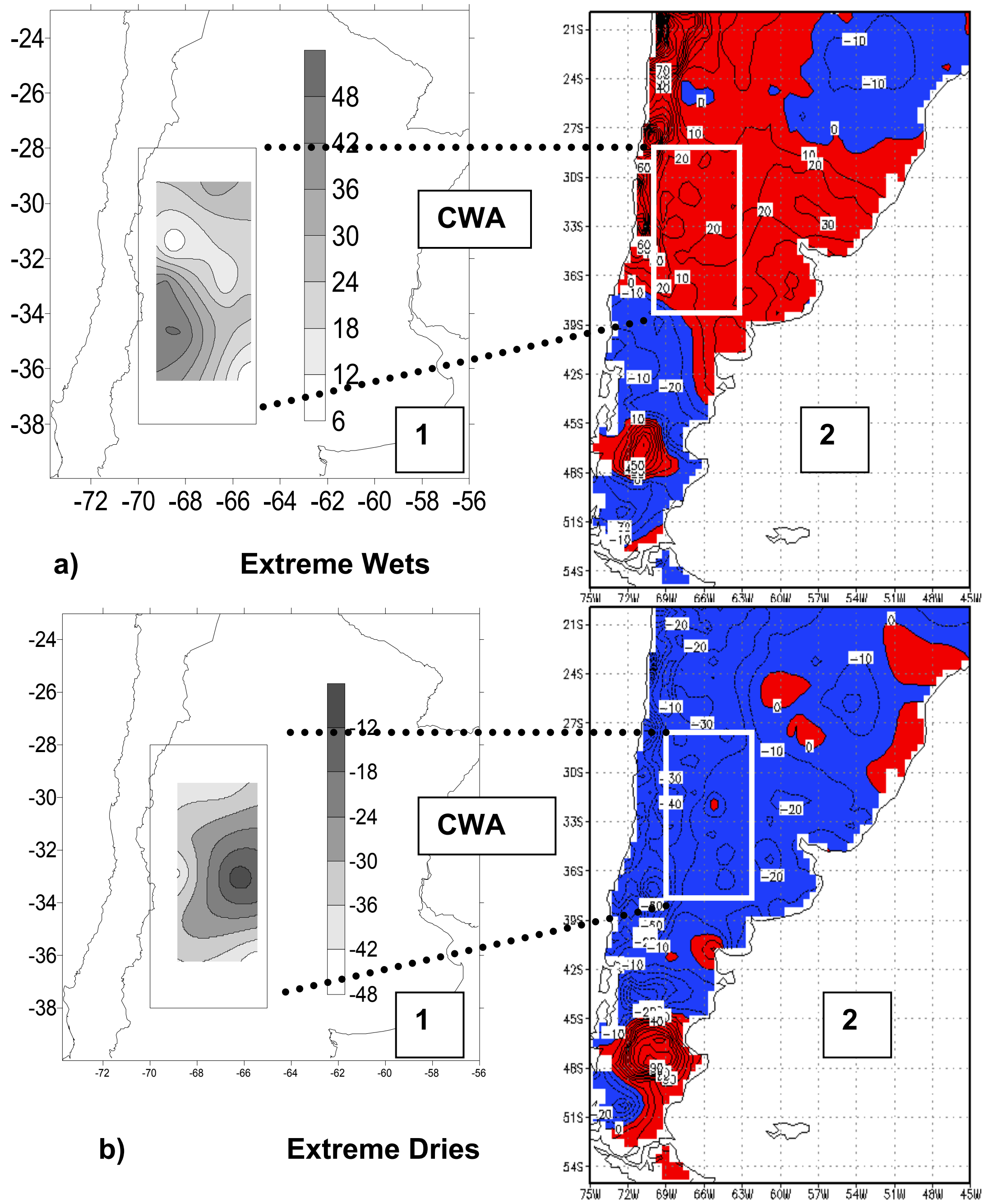

Figure 8: Idem Figure 3, but for extreme wet and dry summers in the period 1977/78-1997/98 (pos-1977).

The before means that an extreme wet summer in the period 1977/78-1997/98 shows spatial coherence of precipitation with subtropical Argentina, to the north of 40°S, whereas in the period 1958/59-1976/77, the coherence is recorded with northern Patagonia up to 45°S.

The composite anomalies of geopotential height for extreme wets shows positive values over the east of the continent, the South Atlantic basin and southern areas of the South Pacific and negative values in the subtropical South Pacific in lower troposphere (Figure 9.a). This means strengthening of the western flank of the SAA over the continent and its extension towards higher latitudes with diminution of the westerlies (less cyclonic activity). The SPA appears to be weakened at subtropical latitudes and displaced toward higher latitudes. The net anomalous mass distribution (high in the South Atlantic basin and low in the South Pacific basin at subtropical latitudes) cooperates to generate a

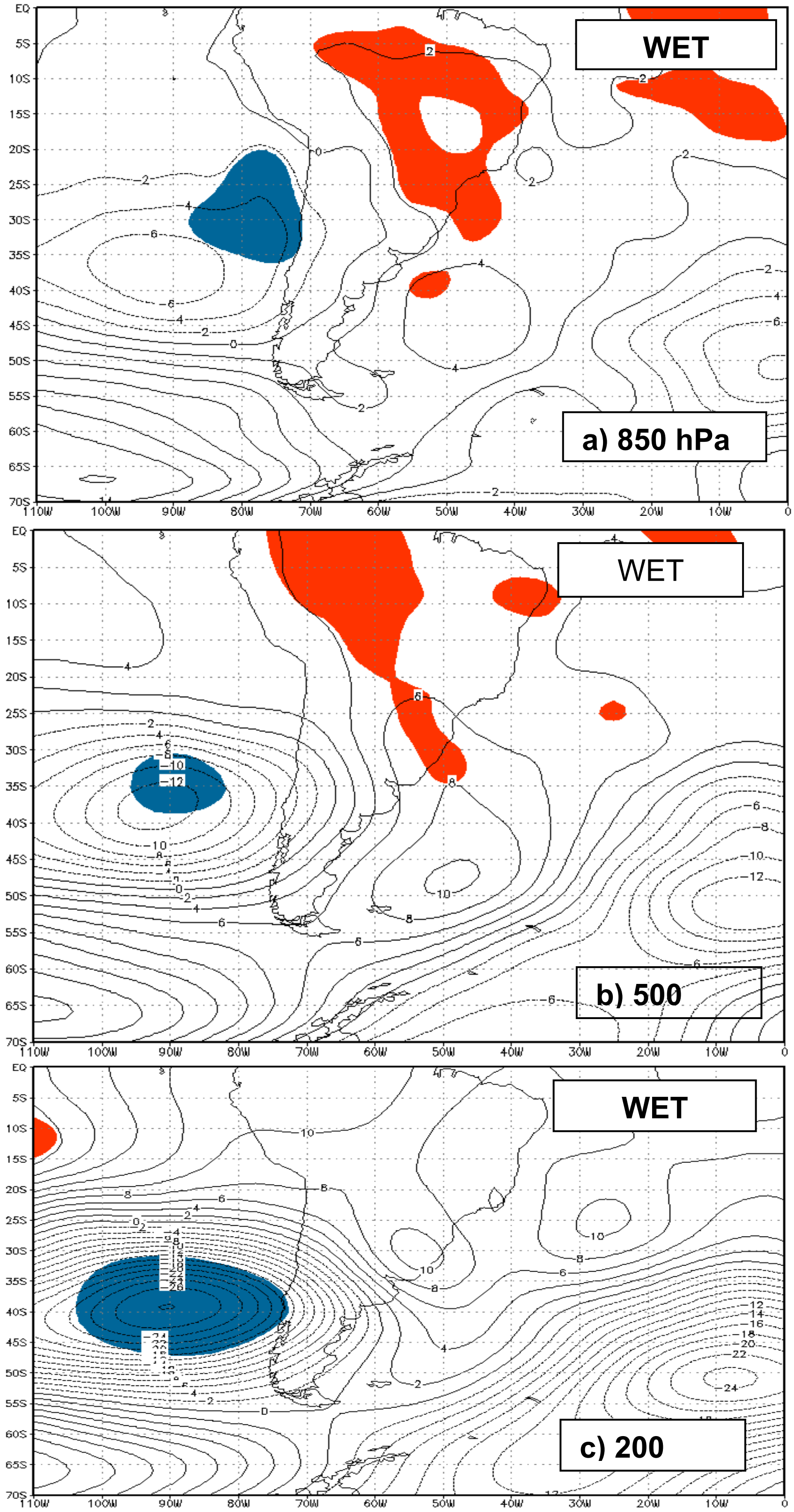

Figure 9: Idem Figure 4, but for extreme wet summers in the period pos-1977.

meridional anomalous flow from the north towards subtropical Argentina. From mid to upper troposphere, the configuration of composite anomalies produces a short subtropical wave that favors the upward motion over subtropical Argentina and, so, over CWA (Fig. 9.b and .c).

The positive composite anomalies of specific humidity in lower troposphere (Fig. 10) are consistent with raise of positive anomalies of precipitation in CWA and subtropical Argentina. These anomalies are associated with the northerly mass flow anomaly up to 30°S and with an easterly-northeasterly component between 30° and 40°S. The moisture transport in this case is from the South Atlantic and the tropical latitudes of South America towards CWA. In the Amazonia the anomalous mass flow shows an exacerbation of the easterlies which turn south towards subtropical latitudes.

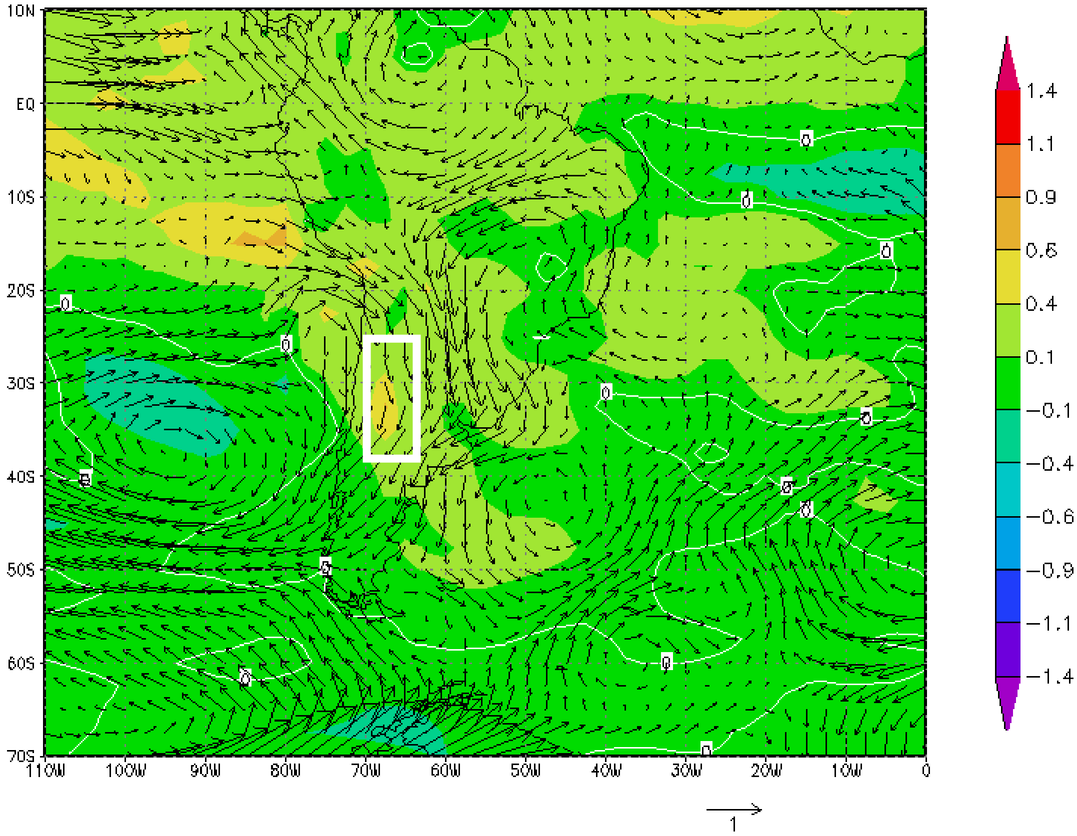

Figure 10: Idem Figure 5, but for extreme wet summers in the prod pos-1977.

The composite anomalies of geopotential height for extreme dries show an inverse pattern to that of extreme wets, although not exactly the opposite (Fig.11). The negative values in the South Atlantic in lower troposphere (Fig. 11.a) indicate a weakening of the western flank of the SAA. In the South Pacific, the positive anomalies at subtropical latitudes point out a strengthening of the SPA and the negative values southwards shows intensification of the westerlies (more cyclonic activity). At mid and upper levels (Fig. 11.b and .c), the configuration of the anomalies shows a wave-train structure (a high in the Pacific, a low the subtropical continent) that favors conditions of differential anticyclonic vorticity advection with associated downward motion over CWA.

The composite anomalies of specific humidity in the lower troposphere are consistent with the negative anomalies of precipitation observed in subtropical Argentina and Patagonia with the lowest values in CWA (Fig. 12). The anomalous mass flow is predominantly from the south in CWA and south-west in northern Patagonia, with a certain anticyclonic rotation in the north of the CWA that may weaken the climatic northwestern Argentina low settled in that location (Seluchi et al. 2003).

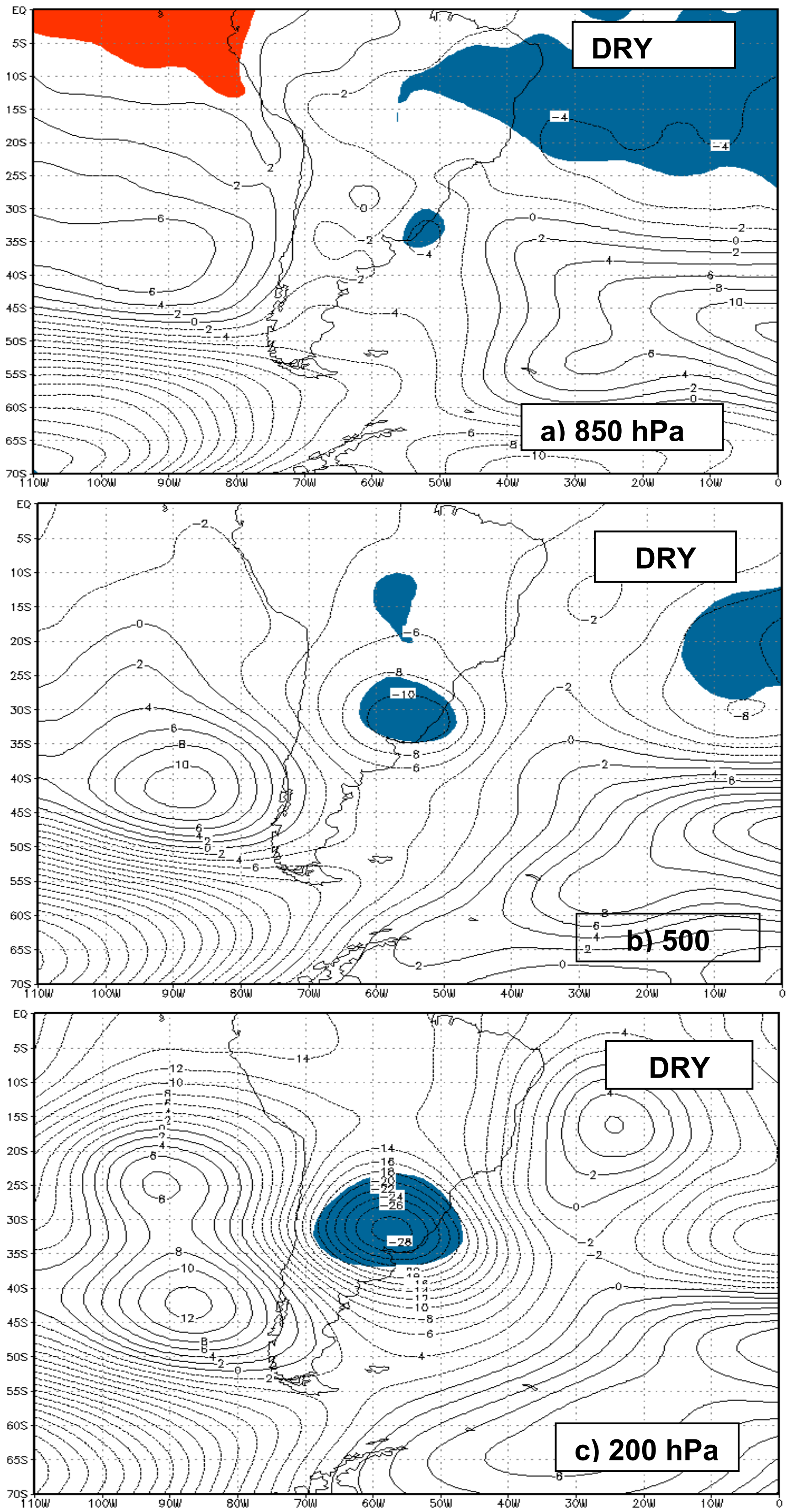

Figure 11: Idem Figure 4, but for extreme dry summers in the priod pos-1977.

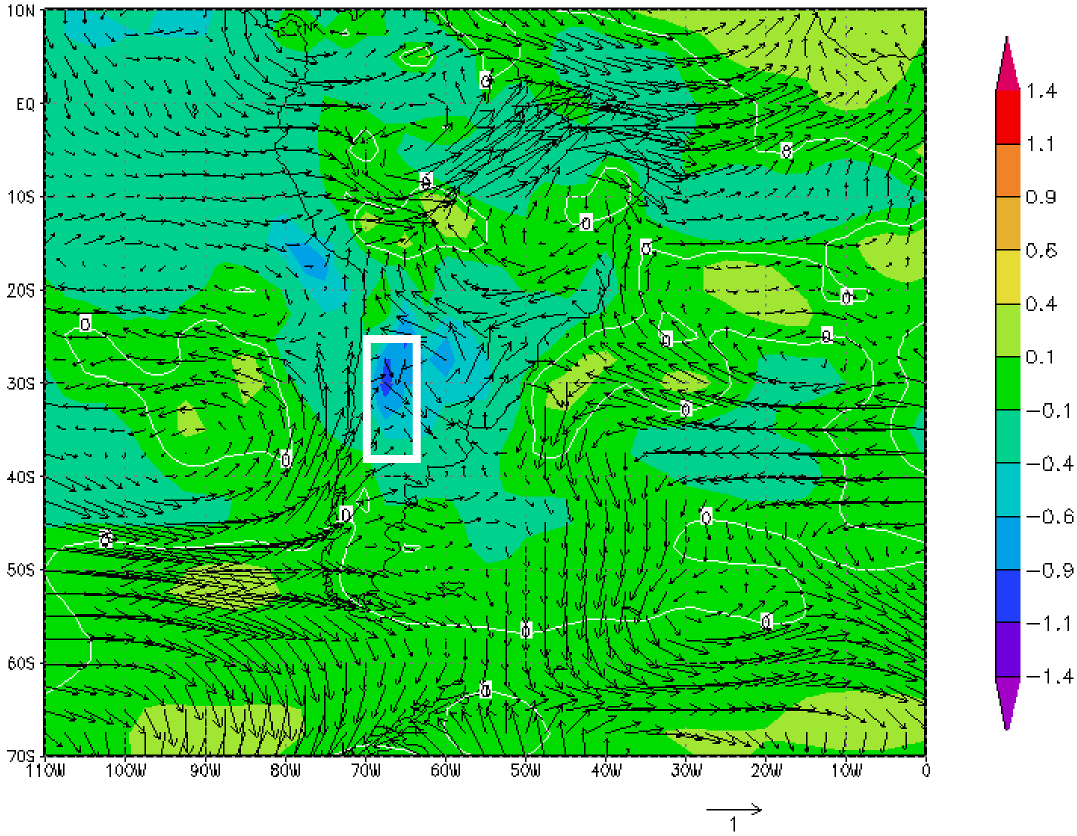

Figure 12: Idem Figure 5, but for extreme dry summers in the period pos-1977.

4. CONCLUSIONS

We have found differential features in the atmospheric circulation that characterize the extreme wet and dry summers and also the changes in those features after the austral summer 1976/77. The main features can be summarized as follows:

For the period pre-1977:

An extreme wet summer is associated to:

- Dynamical (baroclinic) structure of anticyclonic anomaly in lower troposphere located over central Patagonia and adjacent ocean. It implies weakening of the westerlies (less cyclonic activity).
- Positive anomaly of moisture in lower troposphere.
- Easterly mass flow anomaly from the South Atlantic, south of 30°S, related to possible moisture transport.
- Upward motion over CWA associated to a subtropical short wave structure that propitiates differential cyclonic vorticity advection (upper trough right to the west of the Andes).

An extreme dry summer is associated to:

- Dynamical (baroclinic) structure of cyclonic anomaly in lower troposphere over southeastern Patagonia and adjacent ocean. It implies strengthening of the westerlies (more cyclonic activity).
- Negative anomaly of moisture in lower troposphere.
- South-southwesterly mass flow anomaly from the South Pacific crossing the Patagonian Andes, associated with possible adiabatically-dried air masses transport.
- Downward motion over CWA associated to a subtropical short wave structure that propitiates differential anticyclonic vorticity advection (upper ridge right to the west of the Andes).

For the period pos-1977:

An extreme wet summer is associated to:

- Dynamical structure of anticyclonic anomaly in lower troposphere over subtropical/tropical South America and South Atlantic together with another cyclonic structure in the South Pacific that propitiates northerly anomalous flow due to the anomalous mass distribution generated. This is, extension and strengthening of the western flank of the SAA over the continent and weakening of the SPA.

- Positive anomaly of moisture in lower troposphere.
- North-northeasterly mass flow anomaly with possible moisture transport from the subtropical/tropical South Atlantic and Amazonia.
- Upward motion over CWA associated to a subtropical short wave structure that propitiates differential cyclonic vorticity advection (upper trough right to the west of the Andes).

An extreme dry summer is associated to:

- Dynamical structure of cyclonic anomaly in lower troposphere over subtropical/tropical South America and South Atlantic together with another anticyclonic structure in the South Pacific. This propitiates the strengthening of the SPA, weakening of the SAA over the continent and possible weakening of the climatic Northwestern Argentina low.
- Negative anomaly of moisture in lower troposphere.
- South-southwesterly mass flow anomaly from the South Pacific crossing the Patagonian Andes, associated with possible adiabatically-dried air masses transport.
- Downward motion over CWA associated to a wave-train structure that propitiates differential anticyclonic vorticity advection (upper ridge right to the west of the Andes).

In addition, the extreme wet summers in the period 1977/78-1997/98 shows spatial coherence of precipitation with subtropical Argentina, to the north of 40°S, whereas in the period 1958/59-1976/77, the coherence is recorded with northern Patagonia up to 45°S. The results suggest an apparently change in the atmospheric circulation over South America during mid-1970s that can have caused the change in the areas of influence upon the extreme summers in CWA. The summer precipitation before 1976/77 seems to be related to the atmospheric circulation of mid-latitudes while afterwards, it seems to be related to the atmospheric circulation of subtropical/tropical latitudes.

Acknowledgements

This research was funded by grants of the University of Buenos Aires, UBA 01x095, and of the National Research and Technique Council, PIP 5006.

References

Agosta, E.A., Compagnucci, R.H. and Vargas, M.W. 1999:CAbmios en el r´gimen interanual de la precipitación en la región Centro-Oste de Argentina. Meteorol. 24 (1 y 2), 63-84.

Compagnucci, R.H., Agosta, E.A. and Vargas M.W., 2002: Climatic change and quasi-oscillations in central-west Argetnina summer precipitation: main features and coherent behaviour with southern African region. Cli. Dyn. 18, 421-435.

Ebbesmeyer C.C., Cayan D.R., McLain D.R., Nichols F.H., Peterson D.H. and Redmond T. 1991: 1976 Step in the Pacific Climate: Forty enviromental changes between 1968-1975 and 1977-1984. Proceeding of the 7th Annual Pacific Climate PACLIM, Workshop, April 1990, Eds. Betancourt, J.L. y V.L. Tharp, Californian Dep. of Water Resources, Interagency Ecological Studies Program, Tech. Rep. 26, 115-126.

Garreaud, R. D. and D. S. Battisti, 1999: Interanual ENSO and interdecadal ENSO-like variability in the S. Hemisphere. J. Climate. 12, 2113-2123.

Kistler, R., E. Kalnay, W. Collins, S. Saha, G. White, J. Woollen, M. Chelliah, W. Ebisuzaki, M. Kanamitsu, V. Kousky, H. van den Dool, R. Jenne, and M. Fiorino, 2001: The NCEP-NCAR 50-Year Reanalysis: Monthly Means CD-ROM and Documentation. Bull. Amer. Meteor. Soc., 82, 247-268.

Mantua, N. J., S. R. Hare, Y. Zhang, J. M. Wallace, and R. C. Francis, 1997: A Pacific interdecadal climate oscillation with impacts on salmon production. Bull. Amer. Meteor. Soc., 78, 1069-1079.

Namias, J., 1978: Multiple causes of the North American abnormal winter 1976-1977. Mon. Wea. Rev., 106, 279-295.

Seluchi, M. Saulo, C.A., Nicolini, M. And Satyamurti, P. 2003: TheNorthwestern Argentinean Low: a study of two typical events. Mon. Wea. Rev., 131, 2361-2378.

Trenberth 1995: Atmospheric circulation climate change. Climatic Change, 31, 427-453.

Zhang, Y., J. M. Wallace, and D. Battisti 1997: ENSO-like interdecadal variability: 1900-93. J. Climate, 10, 1004-1020.