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Atmospheric circulation features associated to Argentinean Andean rivers discharge variability

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[1] Winter atmospheric circulation patterns and their relationship to runoff variability in the Atuel and Chubut rivers of Argentina are analyzed. The most important atmospheric low levels condition associated with high (low) Atuel discharges is the weakening (strengthening) of the mean atmospheric flow, while the same feature is displaced 5° southward for Chubut. At high levels, results suggest the existence of a NW-SE direction wave pattern extending from Australia to the South Atlantic, favoring positive (negative) pressure anomalies West of the Drake Passage, which deflect the storm tracks northward (southward) and hence increase (decrease) precipitations and subsequent Atuel discharges. In contrast, Chubut discharges are mainly controlled by a shorter wave pattern along the subtropical Pacific, which zonally crosses South America. This pattern helps to maintain low (high) pressure anomalies off the Chilean coast at the upper-river basin latitude for high (low) Chubut runoffs. **Citation:** Araneo, D. C., and R. H. Compagnucci (2008), Atmospheric circulation features associated to Argentinean Andean rivers discharge variability, *Geophys. Res. Lett.*, *35*, L01805, doi:10.1029/2007GL032427.

1. Introduction

[2] The upper basins of the Argentinean Andean rivers are located just East of the international border between Argentina and Chile. Although the socio-economy of the eastern semi-arid piedmont is affected by their runoff fluctuations, the variability of the atmospheric and/or oceanic conditions related to the discharge of these rivers has been rarely considered in the literature [e.g., *Minetti and Sierra*, 1989; *Berri and Flamenco*, 1999; *Waylen et al.*, 2000; *Compagnucci et al.*, 2000; *Masiokas et al.*, 2006].

[3] The discharge of rivers in the Cuyo region (28°S to 37°S) (Figure 1) are highly correlated, with nearly all their volume released in November–March. They are dominated by the snowmelt of the winter snowfall-storage over the high Andes [*Compagnucci and Vargas*, 1998]. However, in northern Patagonia (NP) (37°S to 46°S), river discharges are highest from June to December, with mixed hydrological regimes: one first maximum in winter and a second one in spring, mainly due to the winter rainfall and snowmelt, respectively [*Compagnucci and Araneo*, 2007]. Consequently, in spite of the different hydrological regimes of Cuyo and NP rivers, their interannual runoff variability largely depends on winter atmospheric conditions.

[4] According to *Compagnucci and Araneo* [2005], although river discharge within each region is relatively homogeneous both temporally and spatially, runoffs in each one of these regions are statistically independent from those corresponding to the other region. The correlation coefficients for the Atuel and Chubut rivers, taken as hydrological regime patterns for Cuyo and NP, respectively, are 0.3 for annual discharges and 0.12 for monthly runoffs.

[5] The precipitation variability in lowland Central Chile is correlated with the snow accumulation on the high Andes between 30°S and 40°S [*Compagnucci and Vargas*, 1998; *Falvey and Garreaud*, 2007]. *Montecinos and Aceituno* [2003] showed that increased blocking episodes over the Amundsen-Bellingshausen Seas during El Niño events are strongly connected to wet conditions during winter in central Chile, while dry conditions in winter-spring are induced by a strengthening of the SE Pacific semi-permanent anticyclone with southern storm track migration during La Niña events. Furthermore, particularly the Mendoza River streamflows are likely to fall above (below) average during the mature phase —November-March— of El Niño (La Niña) events, since winters before these events tend to have abundant (deficient) snowfalls in the Central Cordillera and the associated atmospheric circulation presents a major meridional (zonal) component at mid latitudes [*Compagnucci and Vargas*, 1998].

[6] This study enhances our knowledge of the different features of whole troposphere circulation associated with the wide variability observed in the Argentinean Andean rivers, using Atuel and Chubut rivers as patterns for Cuyo and NP rivers runoffs respectively.

2. Data and Methodology

[7] Atuel (from July 1906 to June 2004) and Chubut (from April 1943 to March 2004) monthly streamflows at La Angostura (35°05′57″S; 68°52′26″W; 1200 m a.s.l.) and Los Altares (43°51′00″S; 68°30′00″W; 275 m a.s.l.) gauges, respectively, were provided by the Argentinean Water Resource Administration.

[8] Monthly geopotential heights (HGP, in mgp), wind vectors (V, in m/s) and specific humidities (H, in g/kg) at 1000, 500 and 200 hPa levels in a global regular 2.5° × 2.5° latitude-longitude grid; and velocity potential (Chi, in m^2/s) and streamfunction (Psi, in m^2/s) at σ = 0.995 and σ = 0.2582 in a global T62 Gaussian grid (192 × 94), were obtained from the NCEP Reanalysis 1 dataset of NOAA's Climate Diagnostics Center. The period 1958–2004 is analyzed.

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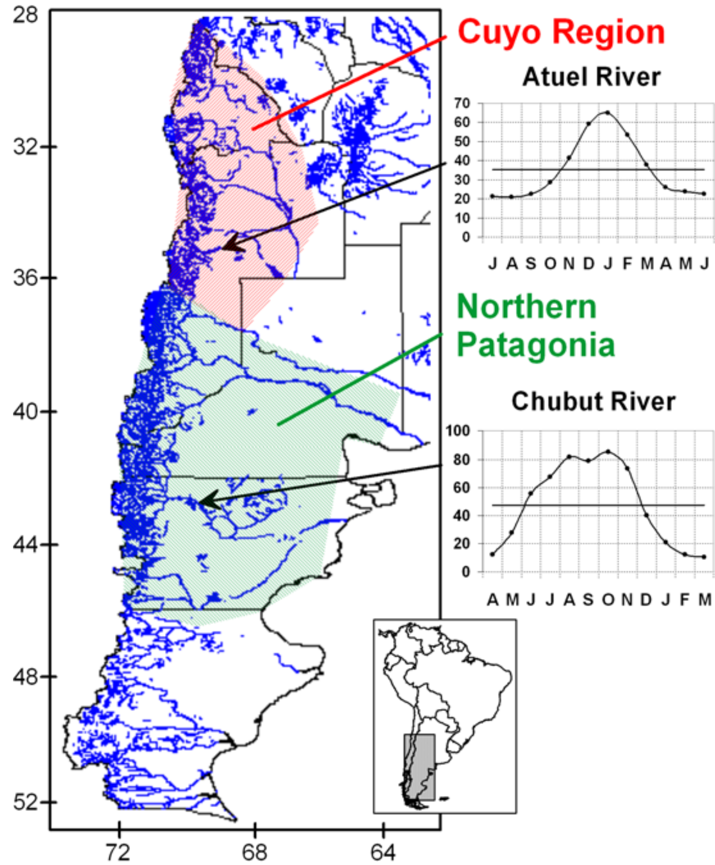

Figure 1. Geographic location of Cuyo and NP regions. The Atuel and Chubut rivers are indicated together with their hydrograms for the period 1943–2003. Horizontal lines in the hydrograms represent the mean streamflows.

[9] Lagged correlation fields (lags from 0 to 12 months) between the meteorological variables and the November–March and June–November streamflows were calculated for the Atuel and Chubut rivers, respectively. As the discharges during these months represent 73% of the total annual runoff for both rivers, they can be considered good estimators of the whole interannual variability. Correlations with the wind vector were calculated by components analyzing the vector $\vec{r} = r_u \cdot \hat{i} + r_v \cdot \hat{j}$, where r_u and r_v are the correlation coefficients between streamflow and the zonal and meridional wind components, respectively. Correlation coefficients significantly different from zero at 90, 95, 97.5 and 99% levels were determined using the t-student test. The $\vec{r}$ vectors were considered significant when at least one of their components, r_u or r_v, is higher than the critical value at the 95% significance level.

3. Results

[10] Monthly lagged correlations made it possible to detect the delay for which correlation values are maximized over wide geographical areas including South America (SA) and adjacent oceans. Highest correlation coefficients were obtained when the discharge of November–March for Atuel and June–November for Chubut were respectively correlated with the preceding May–September (6 months lags) and May–October (1 month lag) averaged meteorological variables.

3.1. Geopotential Height and Wind Vector

[11] Figure 2 shows the correlation fields corresponding to the geopotential height and wind vector at 1000 hPa (Figure 2, top), 500 hPa (Figure 2, middle) and 200 hPa (Figure 2, bottom) levels, for Atuel (Figure 2, left) and Chubut (Figure 2, right).

[12] At low levels, positive correlations can be observed over the Drake Passage for both rivers, although the values are larger and shifted northward for Atuel. Wind correlation vectors exhibit a circulation associated with a high-pressure center in the region. This feature implies anomalous eastern winds or a strong westerlies reduction for discharge excess (vice versa for deficit). The reduction of the westerlies dominates almost all Patagonia South of 42°S for Atuel, while it is only restricted to the southern Patagonia (South of 48°S) for Chubut. High correlations with southern (northern) winds East of the Drake Passage is observed for Atuel runoff excess (deficit) conditions, indicating air advection from (towards) the Pole over Patagonia. However, that is not observed for Chubut. At high levels, correlations over the Amundsen-Bellingshausen Seas remain significantly high for Atuel while they disappear for Chubut. Additionally, this center is shifted westward at high levels with respect to surface (about 8–10° long. between 500 and 1000 hPa), which suggests the presence of dynamic systems (cold low/warm high pressures in the case of river discharge deficit/surplus) going through these latitudes, more frequently than normal.

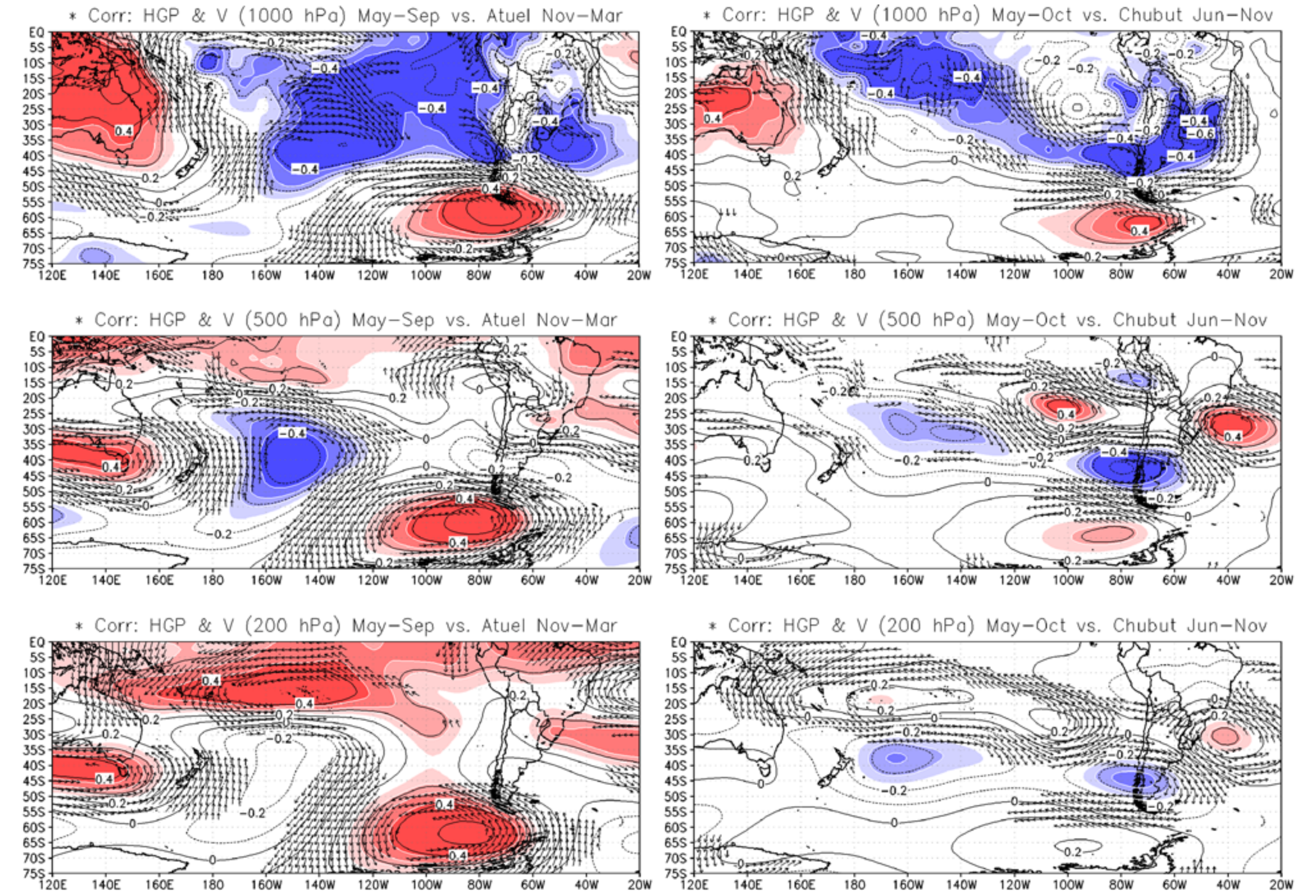

Figure 2. Correlation fields between the mean discharge of (left) November–March for Atuel and (right) June–November for Chubut rivers and the preceding May–September and May–October mean geopotential heights and wind vectors at (top) 1000 hPa, (middle) 500 hPa, and (bottom) 200 hPa levels. Shaded areas correspond to significant values at 90, 95, 97.5, and 99% levels. For wind correlation vectors, only those with at least one significant component —u or v— at the 95% level were included.

[13] Negative correlations crossing the continent at mid latitudes are observed for both rivers at low levels, suggesting a more frequent passage of low pressure systems crossing the Andes from the Pacific for wet conditions and a strengthening of the semi-permanent Pacific and Atlantic anticyclones for dry events. Negative correlations over vast regions of the subtropical Pacific are also recorded for both rivers. However, negative values are greater for Chubut near the continent, with a maximum at 45°S on the Chilean coast, whereas the maximum is weaker and located farther north (39°S) for Atuel. The area with negative values splits into two centers located East and West of the continent. Between both maximums, an anticyclonic circulation is observed over central Argentina which is associated with a relative high pressure for positive discharge anomalies. Wind correlations also exhibit a cyclonic circulation extended from the negative center on the Atlantic towards Paraguay. For river discharge deficits, these circulations are opposite (cyclonic circulation associated to relative low pressure over central Argentina, with anticyclonic circulation extending from the positive center on the Atlantic coming from Paraguay to SW Argentina), associated to the strengthening of oceanic anticyclones and the deepening of the continental low pressure in NW Argentina.

[14] Over the Atuel basin (35°S, 70°W) a NW airflow from the subtropical Pacific is associated with runoff excesses (vice versa for deficits). For Chubut, the geopotential negative correlation center extends from the Chilean coast South of 40°S curving NE towards Uruguay, suggesting that maximum river discharge in NP is related to low pressure systems crossing the Andean Cordillera without discontinuity (since the Andes are lower at these latitudes). As they reach the La Plata River, a secondary cyclonic center indicates a link between maximum discharge in Chubut River and frontal systems over this region, similar to that observed for Atuel River. A NW airflow over the Chubut basin is observed coming from higher latitudes than that observed for Atuel. For river discharge deficit conditions these circulation features invert, with high pressure crossing the continent at mid-latitudes, which inhibits the frontal system's passage along the studied river basins and exacerbate westerlies in Patagonia.

[15] On the central Pacific at 1000 and 500 hPa levels, a negative correlation center is observed at 140°W–40°S for the Atuel. At 500 hPa, this center, together with one over the South Atlantic and two positive centers over the Amundsen-Bellingshausen Seas and Southern Australia, suggest the existence of a stationary wave train that crosses

the Pacific in NW–SE direction. Instead, for Chubut, negative correlations reach the basin from the tropical western Pacific at low levels, but the wave train previously described is not observed at 500 hPa. However, a shorter wave train formed by alternating negative (at 160°W–30°S and Western Patagonia) and positive (at 100°W–25°S and 40°W–30°S) centers occur over lower latitudes. Although reduced in intensity, both the Atuel and Chubut wave trains can also be observed at 200 hPa.

[16] Negative correlation centers at low levels and positive correlation centers at high levels are observed over the tropical Pacific (~15°S–160°W), suggesting the presence of warm low (cold high) pressures over this region under runoff excess (deficit) conditions for both rivers.

3.2. Streamfunction, Velocity Potential, and Specific Humidity

[17] Correlation fields corresponding to the streamfunction, velocity potential and specific humidity provide additional information to identify other circulation features (Figure 3). To facilitate interpretation, vectors representing the associated non-divergent (in Figures 3a and 3b) and non-rotational (in Figures 3c and 3d) wind fields are also shown.

[18] At low levels, for both rivers, positive centers are displayed over the South American coastlines, related to the negative ones described for the geopotential height (Figure 2) at the same locations. However, over the Amundsen-Bellingshausen Seas, the geopotential positive centers are weaker in the streamfunction feature. Moreover, although the Atuel geopotential correlations over this region remained significant at high levels, they are barely significant for the streamfunction at σ = 2.582 and a weak anticyclonic circulation can be recognized at 200 hPa.

[19] At high levels for Chubut, the geopotential negative center observed over Patagonia is also present for the streamfunction (as positive correlations), showing the close association between the anomalous cyclonic (anticyclonic) circulation over the region and the runoff excess (deficit). Additionally, the suggested wave train crossing the Pacific in NW-SE direction towards the South Atlantic observed by the wind vector correlations for Atuel at 200 hPa is also recorded in the streamfunction. However, it is interesting to note that the wave train is reliable on the positive centers for both variables (i.e. centers with associated anticyclonic and cyclonic circulations for geopotential heights and streamfunction, respectively) since negative centers do not show significant values.

[20] As in geopotential height and wind vector patterns, over the tropical Pacific (~15°S–160°W), the rotational wind component reveal the occurrence of cyclonic circulations on surface and anticyclonic ones at high levels, linked to the presence of anomaly warm low (or cold high) pressures over the region.

[21] The occurrence of moisture advection over the Atuel basin at low levels is revealed by positive correlations with the specific humidity at 850 hPa and the non-divergent wind component in NW- SE direction that affects the region from the Pacific.

[22] Regarding the velocity potential, at low levels (σ = 0.995), positive correlations are observed over and adjacent to SA, indicating an air convergence associated with the described anomalous low-pressure systems over the region (Figures 2 and 3c) for excess river discharge. Conversely, for discharge deficits, the atmospheric patterns reverse, with divergence associated with the strengthening of the Pacific and Atlantic semi-permanent anticyclones.

[23] Linked to the geopotential positive correlations center over the Drake Passage, negative correlations with velocity potential are observed at low levels, indicating the presence of a divergence (convergence) area for river discharge excesses (deficits).

[24] The convergences observed at low levels are associated with divergence at high levels over the South and Central Pacific for Chubut, and include SA and a large part of the South Atlantic for Atuel. Furthermore, a convergence area at high levels linked to a divergence one on surface is observed over Australia and New Zealand, especially for Atuel. This feature is related to the subsidence (convection) due to the presence of high (low) pressure at low levels (Figure 2) during streamflow excesses (deficits).

[25] Positive (negative) correlations between discharge and specific humidity are recorded on areas where air converges (diverges) and/or northern (southern) flows are observed. Negative correlations centered East of New Zealand and East of the Brazilian tropical coast (~10°S–20°W) are observed for Atuel, related to southern flows (Figure 3a) and to divergences (Figure 3c) associated with surface anticyclonic anomalies (Figure 2), respectively. Extended regions with positive correlations are observed across the tropical South Pacific and from SE Brazil to the subtropical Atlantic over the South Atlantic Convergence Zone (SACZ). The band extending across the tropical Pacific in NW-SE direction from ~10°S–170°E to ~20°S–90°W is associated with moisture advection from the equator (Figure 3a) and air convergence (Figure 3c)—, while the centers over the Peruvian coasts and at ~40°S–100°W are also related to air convergence (Figure 3c). In the former, this pattern implies a moisture advection from the equatorial Pacific towards the Atuel basin for high discharges. Moisture positive correlations in the SACZ region, coupled with convergence and cyclonic circulation over La Plata River and adjacent areas, might indicate the presence of frontal zones with moisture convergence linked to cyclonic activity for high discharges. Likewise, this feature is observed for the Chubut River, together with a band of positive correlations crossing the tropical Pacific in NW-SE direction also associated to air convergence (Figure 3c) and flow from the equator (Figure 3a). Finally, moisture negative correlation centers are observed for Chubut over the area near New Zealand, the tropical Atlantic and the Drake Passage, all of them associated with air divergence (Figure 3c).

4. Concluding Remarks

[26] Atuel and Chubut rivers discharge fluctuations are related to atmospheric circulation variability during the cold season, mainly in the areas West of the Drake Passage, the South Pacific and over and adjacent to SA.

[27] At *low levels*, high (low) discharges are linked to high (low) pressure anomalies West of the Drake Passage — with associated anticyclonic (cyclonic) and air divergence (convergence) anomalies—, and to a weakness (strength) of

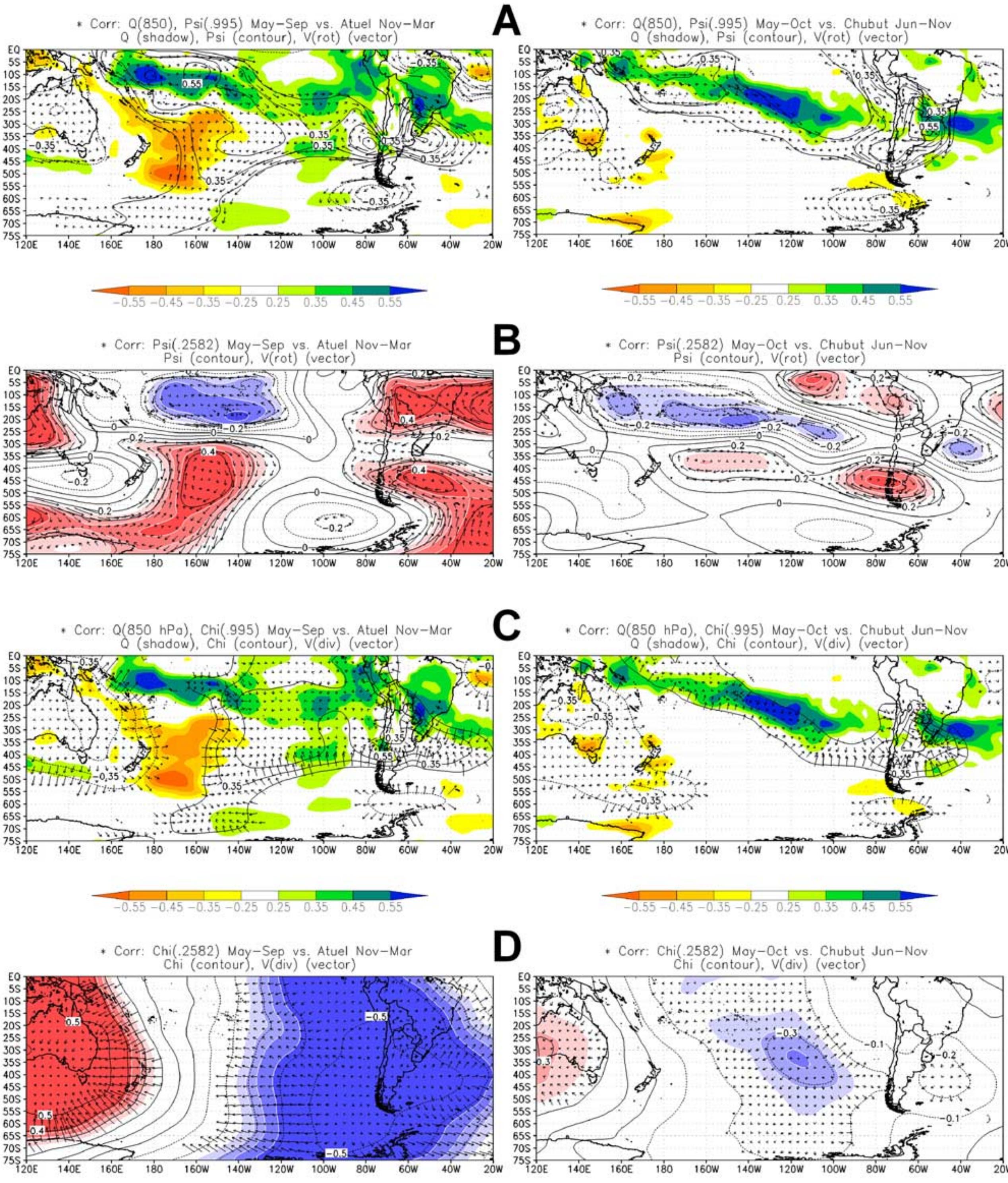

Figure 3. As in Figure 2, but for the streamfunction: (a) $\sigma = 0.995$ and (b) $\sigma = 0.2582$ (outlines) and specific humidity (at 850 hPa, Figures 3a and 3c) (shaded). (c, d) As for Figures 3a and 3b but for the velocity potential. In Figures 3a and 3c only correlation values at 90% significance level are shown. The shading in Figures 3b and 3d corresponds to significant values at 90, 95, 97.5, and 99% levels. Vectors represent non-divergent (Figures 3a and 3b) and non-rotational (Figures 3c and 3d) circulations associated to the correlations with the streamfunction and the velocity potential, respectively.

the pressure fields on tropical and subtropical Pacific —off the Chilean coasts— and over the South Atlantic affecting the Argentinean littoral and the southern Brazilian coast, indicating a weakening (strengthening) of the mean flow conditions. For Atuel high (low) discharge, this feature induces an anomalous circulation in NW-SE (SE-NW) direction from (towards) the subtropical Pacific towards (from) the central Chilean coast with air convergence (divergence) on surface. This circulation pattern increases (decreases) the moisture transport over the Atuel basin (together with an anomalous stream component in SE (NW) direction that can also affect Patagonia). For Chubut, these patterns are displaced 5° southward.

[28] At *high levels*, the Atuel runoff variability is likely related with a wave train pattern extending from Australia towards the South Atlantic in NW-SE direction that helps to maintain positive (negative) pressure anomalies West of the Drake Passage resulting in high (low) river discharge. This pattern was also found by *Montecinos and Aceituno* [2003] linked to increased blocking episodes over the Amundsen-Bellingshausen Seas related to wet conditions in winter on central Chile during El Niño events. Furthermore, this wave feature resembles the Pacific-SA 2-pattern (PSA2), derived from the atmospheric circulation anomalies analyzed at 500 hPa in the Southern Hemisphere during winter, by *Mo* [2000]. Although a pattern similar to the *Mo*'s [2000] PSA1 is observed for Chubut, its runoff variability is mainly related to a shorter wave pattern on the subtropical Pacific that zonally cross SA. This feature contributes to maintain low (high) pressure anomalies off the central Chilean coasts and favors the air ascent (subsidence) and precipitation (or lack thereof) on the river basin for high (low) discharge.

[29] *Vera et al.* [2004] showed that wave patterns as those shown here may appear due to different distributions of South Pacific SST anomalies during El Niño events while *Mo* [2000] showed that PSA1 and PSA2 are associated with the low-frequency and quasi-biennial components of El Niño-Southern Oscillation (ENSO) variability of around 40–48 and 26 months periods, respectively. In addition to the relationships between observed river discharge and ENSO found in the presence of the mentioned wave patterns, the cyclonic and anticyclonic circulations over the tropical central Pacific at low and high levels respectively (Figures 3a and 3b) also provide evidence for a relationship with the presence of anomalous warm low (cold high) pressures over this region for high (low) runoffs. These systems might originate in response to the anomalous warming (cooling) of the ocean during El Niño (La Niña) events. Moreover, the correlation fields for the non-rotational component (Figures 3c and 3d) suggest a link between high (low) river discharge and air uplift (descent) on the eastern and descent (ascent) on the western Pacific, which point to a weakening (strengthening) of Walker circulation for high (low) river discharge, typically observed during El Niño (La Niña) events.

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