Proceedings of 8 ICSHMO, Foz do Iguaçu, Brazil, April 24-28, 2006, INPE, p. 693-702.

SEA SURFACE TEMPERATURE AND ATMOSPHERIC CIRCULATION FEATURES ASSOCIATED TO THE ARGENTINEAN ANDEAN RIVERS STREAMFLOW VARIABILITY

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Abstract

The objective of this paper focuses on revealing the main characteristics of the conditions of Atmospheric Circulation and Sea Surface Temperature (SST) associated with the fluctuations of flow in the Atuel and the Chubut rivers, whose temporal behaviors represent the temporal variations found in the rivers of the Cuyo and North Patagonia regions.

The relationship between streamflows and SST is significant in large areas of the Southern Hemisphere (SH) central Pacific. However, the Atuel variability seems to be highly linked to El niño / Southern Oscillation (ENSO) patterns with strong signal in the tropical-equatorial Pacific and the Indian Ocean, whereas the Chubut seems to be less associated with the ENSO, showing signal restricted to the SH central subtropical Pacific.

High streamflows in the Atuel zone are associated with frequent passage of northwest-southeast oriented lows moving over the subtropical Pacific that induce moisture convergence from lower latitudes and its advection toward the Andean region. The lows reaching the central Chilean coast would produce upward air motion with intense snowstorms in the high mountains and downward air motion with relative high pressures leeward the Andes. Hence, over northeastern Argentina and southern Brazil, a later cyclogenesis would be produced and an increase in baroclinicity linked to a frontal zone with consequent moisture convergence from Brazil, upward air motion and high pre-frontal temperatures. In cases of high streamflows in the Chubut zone, the lows from the Pacific would reach the Chilean coast at higher latitudes, crossing over the natural further low Andes with no discontinuity and transporting moisture from subtropical latitudes.

The subtropical low systems are linked to a remarkable reduction of the westerlies owing to higher frequency of highs from the southern Pacific. Some researchers associate these highs with equatorial SST anomalies and the decadal ENSO-like variability and they may take part of a wave-train from the Indian Ocean extended over the southern Pacific. The wave-train can be observed with the correlation between the Atuel streamflows and the geopotential height, but not for the Chubut streamflows.

Inverse circulation and SST features would be associated to low streamflows in the studied regions.

1. INTRODUCTION

Argentinean rivers, that flow almost parallel from northeast to southeast and whose sources are on the Andes, show flow regimens which depend mainly upon the accumulation of snow on the high peaks and upon the melting of such in the warm seasons: spring and summer. The variability of the inter-annual flow of these rivers has a considerable impact on the economy of these regions and therefore a precise annual overflow forecast is crucial. As a rule, the forecasts of water availability in summer take into account the accumulation of snow, which has fallen in the previous winter. Necessary data is gathered at the very beginning of spring and, therefore forecasts are possible only two or three months in advance. It is expected that further knowledge about the way atmospheric circulation directly or indirectly affects rainfall on high peaks may slightly contribute to improve these forecasts.

The relationship between snow or rain fallen on the Cordillera area and El Niño / Southern Oscillation (ENSO) phenomenon was studied by Compagnucci and Vargas (1998). Considering Mendoza river as a model of Cuyo rivers, the authors state that during the mature stage of El Niño (la Niña) events, flows tend to be over (below) average. In turn, in the winters previous to the mature stage of El Niño (La Niña), when snowfalls take place over (below) average on the Cordillera, the circulation presents a higher meridional component in mid latitudes.

Rutllant and Fuenzalida (1991) and Montecinos and Aceituno (2003), analyzed the inter-annual variability of the winter rainfall in Chile and its relationship with the conditions of

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the equatorial Pacific Ocean. These results are related to the variability of Cuyo rivers, since more winter rainfall in central Chile implies higher levels of rainfall on the high peaks of the Andes (Campagnucci y Vargas, 1998), the region where the sources of the watersheds of Cuyo rivers are located.

The variability of Andean rivers is significant and sensitive to the conditions of the Pacific Ocean, besides being closely related to the forcing or general conditions, which generate rainfall on the Andean high peaks during the winter, as it is indicated in the previously mentioned records and in Berri and Flamenco (1999) about the river Diamante.

From the definition of a modified linear rate correlation coefficient used as a distance measure in an unrotated s-mode Principal Component Analysis, Araneo and Compagnucci (2004a) objectively identified two regions, along the Andes, in which different climatic conditions determine similar hydric regimens. The identified regions are: 1) the area which extends from Jachal river (San Juan province) up to Colorado river (Mendoza province) and 2) the area that stretches from Neuquén river (Neuquén province) as far as Senguer river (Chubut province). The boundary between these two regions is in the whereabouts of the Negro River. The course of the average monthly flows of the Atuel in La Angostura and the Chubut in Los Altares are completely correlated with the corresponding courses of the remaining rivers of the regions 1 and 2 respectively. Figure 1 shows the distribution of the linear correlation coefficient between these rivers and the rest included in this area of study. The dramatic fall of the values of correlation through the boundary between these two regions shows the statistical independence in the characteristics of the temporal variability of the flows observed in the rivers of this area.

The objective of this paper focuses on revealing the main characteristics of the conditions of Atmospheric Circulation (AC) and Sea Surface Temperature (SST) associated with the fluctuations of flow in the Atuel and the Chubut rivers, whose temporal behaviors represent the temporal variations found in the rivers of the previously described regions.

2. DATA AND METHODOLOGY

The data used is as follows: monthly data of the flow of the Atuel at La Angostura gauge station (35º 05’ 57’’S; 68º 52’ 26’’O; 1200 m above sea level) and of the Chubut at Los Altares gauge station (43º 51’ 00’’S; 68º 30’ 00’’O; 275 m above sea level) provided by the ‘Subsecreataría de Recursos Hídricos de la Nación’ (Argentine Hydric Resources Agency). Both records make up a grouping of continuous observations comprising the periods July 1906 to June 2004 for the Atuel and April 1943 to March 2004 for the Chubut.

For the analysis of the atmospheric circulation it has been decided to use monthly and daily data of geopotential height (GPH, in mgp), wind vector (V, in m/s) and specific humidity (H, in g/kg) at the levels of 1000, 850 and 500 hPa, and of Potential Velocity (Chi, in m^2/s) and Stream Function (Psi, in m^2/s) at the level sigma 0.995, with a global coverage in a regular 2.5º X 2.5º latitude-longitude greed, relating to the reanalysis 1 of NCEP, provided by the Climate Diagnostic Center of the NOAA (Kalnay et al.,1996). Even though this database runs from 1948 to 2004, only the 1958-2004 period is analysed since information of radiosonde is available during these years and as a consequence, data is more reliable.

The SST monthly mean data correspond to the Extended Reconstructed Sea Surface Temperature (ERSST) of NOAA, with global coverage above a 2.0º X 2.0º latitude-longitude greed. This data was constructed by using the most recent grouping of SST data from COADS (Comprehensive Ocean-Atmosphere Data Set) and improved through statistic techniques, which allow a stable reconstruction using scarce rates (Smith and Reynolds, 2004).

The lagged correlation fields (i.e. from cero to 12 months) of meteorological variables and the seasonal average flow for the maximum accumulation period (i.e. November–March for the Atuel and May–October for the Chubut; see hydrogram in figure1) are calculated for each river. Correlations with the wind vector are estimated by components analysing the distribution of the correlation vector r=(ru;rv), in which ru and rv are the correlations between streamflow and the zonal and meridional wind components respectively.

Particularly, years 1986 and 1971 are daily analyzed, since they present the peculiarity of being periods in which the Atuel and Chubut streamflow anomalies are visibly inverted (i.e. positive flow anomaly in Atuel and negative in Chubut for 1986 and vice versa for 1971). Seasonal mean anomaly fields and Hövmoller diagrams (May–October period) of the employed meteorological variables are designed for these two years.

3. RESULTS

The annual standardized overflows series (figure 2) for the Atuel (red bars) and the Chubut (blue bars), show the presence of years in which the values of both rivers have opposite signs.

For example, in 1986 the Atuel presents positive overflow anomalies, which exceed a standard deviation (σ) whereas the annual overflow is less than –σ for Chubut. Year 1987 is another example in this respect, even though the anomalies of the Chubut do not exceed –σ. As opposed to this, the years 1945, ‘49, ‘50, ‘51 and ’71 present positive anomalies for Chubut and negative for Atuel. Such results prove true the independence in the behavior of the flows observed in the mentioned regions and the low inter annual variation explained by the rivers of one region for those of the other region. It is also worth mentioning the existence of long periods in which the annual overflow usually stays below the average, for example in the periods 1945-52 and 1954-71 for Atuel and 1985-92 for Chubut, or above, as in 1978-87 for the Atuel and 1977-82 for the Chubut. In most situations also the deficit and surplus periods are different for the chosen rivers.

The correlations between the flow of the Atuel river (November–March) and the meteorological variables pointed out, are maximized with a lag of about 6 months (i.e. averages of the period November- March for the Atuel flow with averages of the previous May–September period for the meteorological variables), proving obvious the predominance of the winter climate conditions over the river summer flow fluctuations. Likewise, the correlations for the Chubut streamflow (June–November) intensify with a lag of around 1 month (i.e. averages for the June–November period for the Chubut flow with averages of the period May–October for the meteorological variables) since the sources of the Chubut river and its tributaries are located in regions where flows not only increase due to thaw but also due to liquid winter rainfall. As a consequence, the flow fluctuations of both rivers result from average climate conditions of both the winter and beginning of spring, the period on which we focus this research.

Figure 3 shows the correlation fields between the seasonal average Atuel flow (November–March) and Chubut flow (June–November) with the seasonal averages (period: May–September and May–October respectively) corresponding to the variables: Geopotential Height (GPH) and Vector Wind (V) in 850 hPa, Stream Function (Psi, in σ=0.995) and Specific Humidity (Q, in 850 hPa), Potential Velocity (Chi, in σ=0.995) and Sea Surface Temperature (SST). Only those significant values (90% of significance) are shown in the graph. For the Wind Vector, the graph only shows those correlation vectors in which at least one of the two components, ru or rv, is significant.

In case of Geopotential Height and Vector Wind, positive correlations are observed for both rivers over the Drake Passage even though regarding the Atuel, the values are higher and its center is located further to the north. The correlations with the Vector Wind exhibit a circulation associated with a high-pressure nucleus in the previously mentioned centre. This grouping might suggest a high correlation with anomalous winds from the East or with a dramatic reduction of the westerlies in cases of flow excess and vice versa. It is worth mentioning that such westerly flow reduction or inversion is located to the south of 42°S in the case of the Atuel (dominating almost the whole territory of the Patagonia) whereas in case of the Chubut it is only restricted to the southern portion of the Patagonia (south of 48°S). To the East of the Drake Passage there is a strong correlation with southerly flow in the Atuel river indicating advection of polar air over the Patagonia, which does not exist for the Chubut. In addition to this, in both cases the significant negative correlations in mid latitudes extend across the continent, which might indicate a close connection between the flow excesses with the frequent passage of low-pressure systems, which cross over the Andean range from the Pacific. These correlation values show a greater magnitude in case of Chubut with maximum located in 45ºS over the Chilean coastline, while as for the Atuel the maximum is located further to the north (39°S) and of lesser magnitude. In this last case, the cores are divided into two negative centres to the East and West of the continent. Between these maximums, over the central region of Argentina, there is an anticyclonic circulation associated with a relative high pressure. The correlations with the wind also show a cyclonic circulation that ranges from the negative core located over the Atlantic towards Paraguay. On the sources of the Atuel (around 70ºO, 35ºS) the correlations with the circulation indicate a NW flow, coming from the subtropical Pacific, associated with flow excesses. As regards the Chubut River, the negative centre ranges from the Chilean coastline to the south of 40ºS curving towards the NE heading to Uruguay. Additionally, regarding the Atuel, there is a centre of negative correlations located over the central Pacific, which together with two centres with positive values, one over Australia and the other over the Drake Passage, constitute a sequence of seasonal waves that cross the ocean from NW to SE. Such sequence is not observed in the case of Chubut River.

The correlation fields obtained for Stream Function, Potential Wind and Specific Humidity, support the results previously described. As for the Atuel, the Stream Function shows two centres of positive correlation (which might represent a cyclonic circulation): one over the Chilean coastline to the north of 40ºS and another over Del Plata River, associated with the negative centres of the GPH already mentioned. Also over this area, the potential wind shows positive correlations, which might represent the air convergence over the region, induced by low pressures, with a subtle divergence to leeward of the mountain range. The cyclonic circulation stretches over almost the whole of the Pacific inducing a humidity advection from the Equator, which reaches the sources of the Atuel from the NW. In mid latitudes of the Western Pacific a strong air advection from the south produces a humidity deficit in this region. Over Drake Passage it is possible to notice the anticyclonic circulation and the divergence of air associated with the positive correlations of GPH mentioned in this area. In case of Chubut, the cyclonic circulation and the air convergence which project from the Pacific reach the mountain range further to the south than in the case of Atuel, going across it, with no interruption and curving towards Del Plata River from the Chilean coastline to the south of 40ºS. In this case, the divergence to leeward of the mountain range observed for the Atuel, does not turn out to be so evident. For both rivers, it is plausible to observe a positive correlations band with the Specific Humidity which crosses the subtropical Pacific, probably associated with the increase of humidity produced by groups of low pressures which move over the ocean towards the mountain range, and another band over the south of Brazil which extends towards the Atlantic, possibly connected with the presence of seasonal fronts associated with the low pressures which cross the mountain range in the case of the Chubut or which generate over Del Plata River in case of Atuel.

The correlations between the SST and the Chubut and the Atuel flows show, in both cases, positive values that are significant in the area of the equatorial Pacific and negative values between 30º and 60ºS, added to positive values in the south Atlantic. It is noticeable that the correlation values for the equatorial /tropical area are fewer for the Chubut ($r>0.35$) than for the Atuel ($r>0.45$). In the latter, the area of significant correlation is much higher and it is clearly located over the region of maximum anomalies of SST during the extremes of the ENSO cycle. These correlations are positive over the Pacific and the Indian and negative to the north of Australia, according to the typical El Niño / La Niña anomalies pattern of SST. In the Chubut, such structure is absent and this suggests scarce or low relation with the ENSO. On the other hand, the Chubut has the higher values of correlation with SST in the area of the central Pacific in subtropical and mid latitudes, positive correlations (with maximum $r>0.55$) between 90º and 130ºO and negative (with minimum $r<-0.55$) between 170º and 130ºO stretching towards the north of Australia over Philippines, and another region over the eastern area adjacent to the Chilean coastline with lower absolute rates ($r<-0.35$) together with correlations of the same sign over the western area of the south Atlantic adjacent to the coastline of the Patagonia. The alternation of negative and positive centres of significant correlation makes up a line, which ranges from the northwestern equatorial, located in the Philippines to the southwest of Patagonia. This structure indicates that negative (positive) anomalies of TSM in the area of the Humbolt stream and in the equatorial area to the north of Australia in mid latitudes induce rainfall over (below) the mean which means bigger (smaller) overflows in the area of the Chubut.

While the AC and SST configurations described and displayed in Figure 3 correspond to cases of high flow in the mountain range, the patterns with opposite sign are associated with events of low flow.

Most of the years in which there are extreme flow anomalies in one of the two examined rivers, present anomalies of the same sign in the other river as well (see Figure 2). However, there are some exceptions such as the year 1986 (with an extreme positive anomaly in the Atuel and negative in the Chubut) and the year 1971 (with a negative anomaly in the Atuel and positive in the Chubut). The mean circulation observed during these years presents opposing configurations.

Figure 4 illustrates the seasonal average anomalies of the absolute value of 500/1000hPa thickness horizontal gradient and GPH in 850 hPa (above); Specific Humidity in 850 hPa, Stream Function and Rotational Wind Component in $\sigma=0.995$ (centre); and Specific Humidity in 850 hPa, Potential Wind and Divergent Wind Component in $\sigma=0.995$ (low); corresponding to the period May-October 1986 (left) and 1971 (right).

In the year 1986, it is possible to observe negative anomalies which extend throughout the Pacific Ocean over subtropical latitudes (between 45º and 25º S) and over the Weddell Sea, to the west of the Antarctic Peninsula. In these centres it is clear to see positive anomalies of absolute value of 500/1000 hPa thickness horizontal gradient (high baroclinicity) which prove the presence of frontal bands associated with these low pressures. In the central Pacific, over high latitudes, there is a core of positive anomalies. This situation might represent a significant reduction both in the semi permanent anticyclone and in the flow of westerlies on the Pacific, as well as an intensification of the westerlies on the South Atlantic. The configurations of Stream Function and Potential Wind show circulations associated with this anomalous pressure field. Over the Eastern Pacific Ocean, in 35ºS, there is an anomalous circulation from the North West, which advects humidity from the subtropical regions towards the sources of the Atuel River. In the Patagonia, however, an anomalous circulation of polar air reaches the region advecting dry air. The corresponding divergent wind field shows patterns associated with the centres of high and low pressure already described, with convergence on the central Pacific Ocean in mid latitudes and the Weddell Sea, as well as divergences on the Pacific Ocean in high latitudes.

In the case of the year 1971, the AC patterns are in general opposite to the previous ones. On the South Pacific there is a centre of negative anomalies of GPH that reaches the Patagonia with a high baroclinicity band that extends towards the south of this region. To the north, a belt of positive anomalies of GPH which runs over the Pacific around the 30ºS reaching the mountain range and generating stability conditions on the Atuel region. To the east of Antarctic Peninsula, there is a centre of positive anomalies with low baroclinicity. The anomalous anticyclonic circulation off the Chilean coastline in subtropical latitudes becomes evident on the rotational wind field with an advection from the south that produces dryness on the Atuel region and continues over the tropical Pacific. The dryness in this area is also benefited from the divergence shown on the Potential Wind field. Also, this field responds to the location of anomalous centres of high and low pressure previously described. In general, for both years, the regions of positive (negative) anomalies of humidity are dominated by flows from north (south) and / or convergent (divergent) ones.

Figure 5 shows the Hovmoller diagrams in a meridional crossection at 100°W for the daily GPH anomalies in 1000 hPa corresponding to the May–October 1986 (A) and 1971 (B) periods. Panels C and D show the temporal averages corresponding to the diagrams of the panels A and B respectively. Panels E, F, G and H are analogous to the previous ones but for the absolute values of 500/1000 hPa thickness horizontal gradient at a 120°W crossection. Regarding the GPH anomalies we can observe a period with negative values from May to August 1986 to the north of 45° S. Positive anomalies are restricted only to the south of 45°S, with maximums which range approximately from 50° and 60° S, mainly at the beginning of May and June, at the end of July and beginning of August. The outcome of this situation is a temporal average which reveals a maximum of positive anomalies around 65°S. In contrast, in 1971 we can observe a period of higher frequency of negative anomalies to the south of 45°S and positive to the north as from mid July. Throughout the previous period there is an alternation of negative and positive anomalies, which cancel one another when taking the temporal average. Regarding the anomalies of the absolute value of 500/1000 hPa thickness horizontal gradient in 1986, there are maximums observed which reach subtropical latitudes throughout the period, mainly around 30°S. Between 70° and 65°S maximums associated with the Polar Front are observed, particularly strong in the period June–October. In mid latitudes there is a considerable reduction of the baroclinic activity with a minimum around 50ºS. On the other hand, in case of 1971, the minimum of baroclinic activity in mid latitudes is no so stressed and the maximums do not reach latitudes as low as they do in the previous case. Furthermore, it is possible to see a band of negative rates to the north of 30ºS which remains the same all throughout the period studied. However, contrary to the previous case, during the winter months, the Polar Front advances towards lower latitudes and locate between 65° y 55° in July and September.

4. CONCLUSIONS

The excesses of streamflows in the Central Cordillera might be associated with the increase in the frequency of low pressures that circulate through the subtropical Pacific in NW-SE direction, which produce a humidity convergence from low latitudes and its advection towards the mountains. A band of high baroclinicity accompanies these systems with convergence of air and humidity in the low layers. When reaching the central Chilean coast they would produce a rise with heavy snowfalls on the peaks and a descent with high relative pressure to leeward of the mountain range and with divergence in low levels. A subsequent ciclogenesis and baroclinicity increase linked to an associated front with a consequent convergence of humidity from Brazil and prefrontal rise would arise over the area of the Argentinian seaboard.

When it comes to flow excesses in the South Range, the low-pressure systems would come from the Pacific reaching higher latitudes and would go across the range without discontinuity.

These systems would haul humidity from subtropical regions of the Western Pacific towards higher latitudes in the range. Such humidity would fall over the range in the Chubut region, while low-pressure systems would cross it and then deviate towards the North East.

In both cases the circulation as a whole goes together with a great reduction of the westerlies, associated with the increase in the frequency of blocking events over the South Pacific. The conditions of flow deficit would take place with circulations associated with inverse patterns to those described in the previous case.

For the analysis in synoptic scale complementary results are obtained from two extreme examples: the year 1986 (with a positive significant anomaly in the Atuel and negative in the Chubut) and the year 1971 (with a negative anomaly in the Atuel and a positive one in the Chubut). In these years, the observed average circulation presents configurations, which are opposed to one another. The conditions of flow excess in the central range and deficit in the south range would be associated with frequent blocking events in the south Pacific which reduce the circulation of the westerlies, deviating the low-pressure systems towards subtropical latitudes and prevent the polar front from moving towards lower latitudes in winter. Low-pressure systems would reach the central range producing instability and humidity advection above the source of the rivers of the region. Meanwhile, in the western flank of the blocking anticyclone situated over high latitudes of the pacific, an important advection of cold dry polar air that would reach the Patagonia inhibiting the rainfalls from falling on the region. The inverse conditions (low pressures above the south of Patagonia coming from the south Pacific with high baroclinicity and the intensification of the semi permanent anticyclone of the Pacific) would explain those cases of high flow in the south range and low flow in the central one. The samples studied do not reveal a special time period in winter for these cases to take place.

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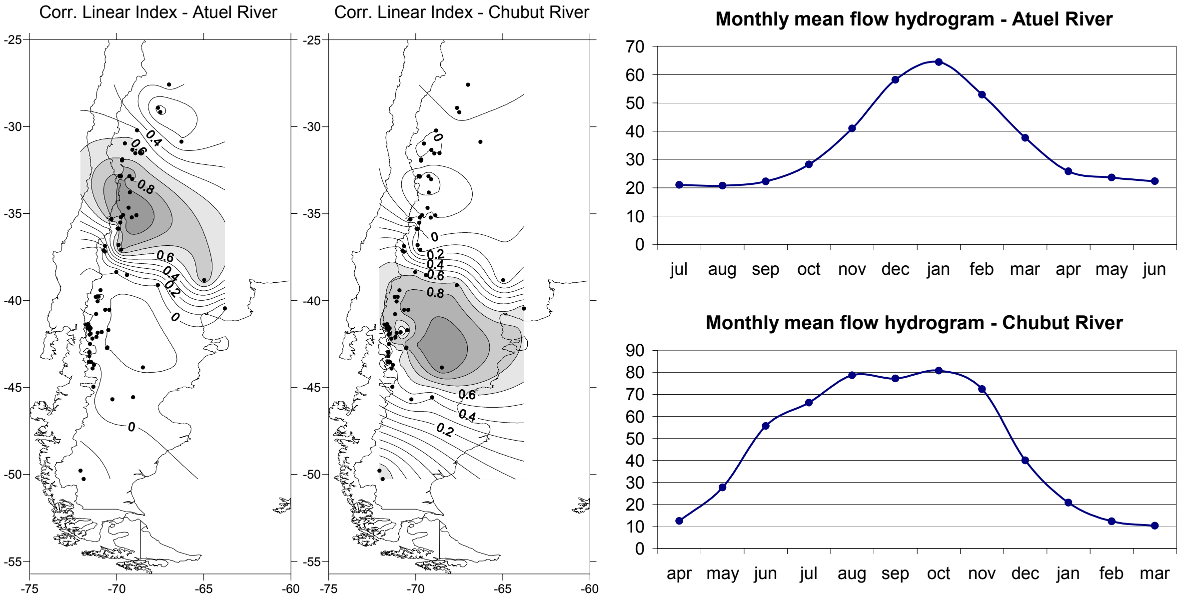

Figura 1. Linear correlation coefficient fields between the Atuel (in La Angostura) and the Chubut (in Los Altares) rivers streamflows, and the other rivers included in the Andean region. Hydrograms based on the 1906-2000 series for the Atuel and 1943-2000 series for the Chubut.

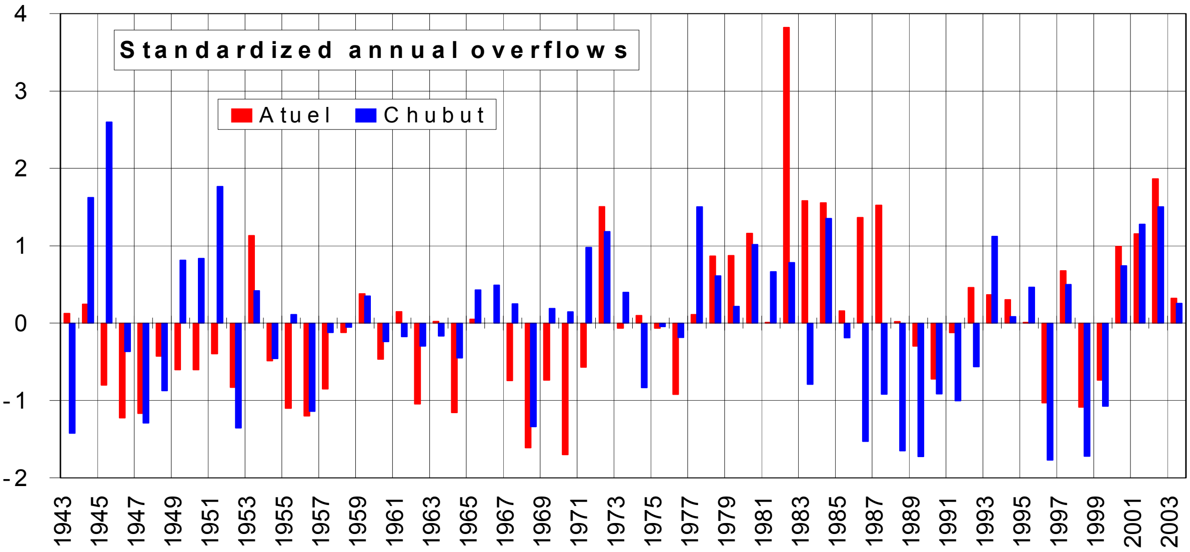

Figure 2. Standardized annual overflows corresponding to the Atuel (red bars) and Chubut (blue bars) flow series. The annual totals are calculated for every hydric year (i.e. July-June for Atuel and April-March for Chubut). The suitable years correspond to the winter of every hydric year.

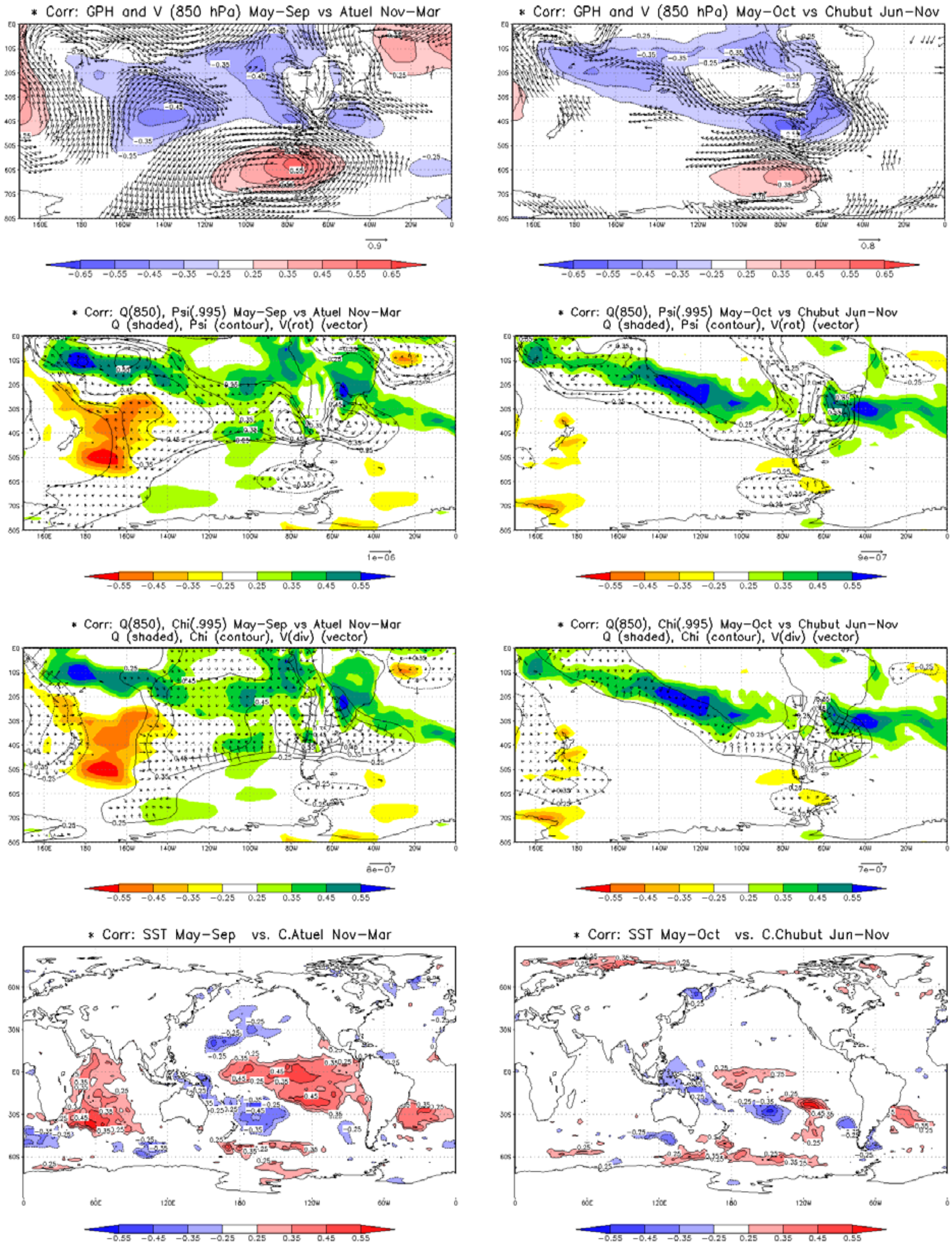

Figure 3. Correlation fields between the seasonal mean flow of the Atuel (Nov.-Mar. period) (left) and of the Chubut (period Jun. Nov.) (right) streamflows and the seasonal anomalies (May.-Sep. and May.-Oct. periods respectively) corresponding to the variables (from above to below): Geopotencial Height in 850 hPa, Stream Function (Psi, in σ=0.995), Specific Humidity (Q, in 850 hPa), Potential Velocity (Chi, in σ=0.995) and Sea Surface Temperature. Only the values up to 90% of significance are plotted.

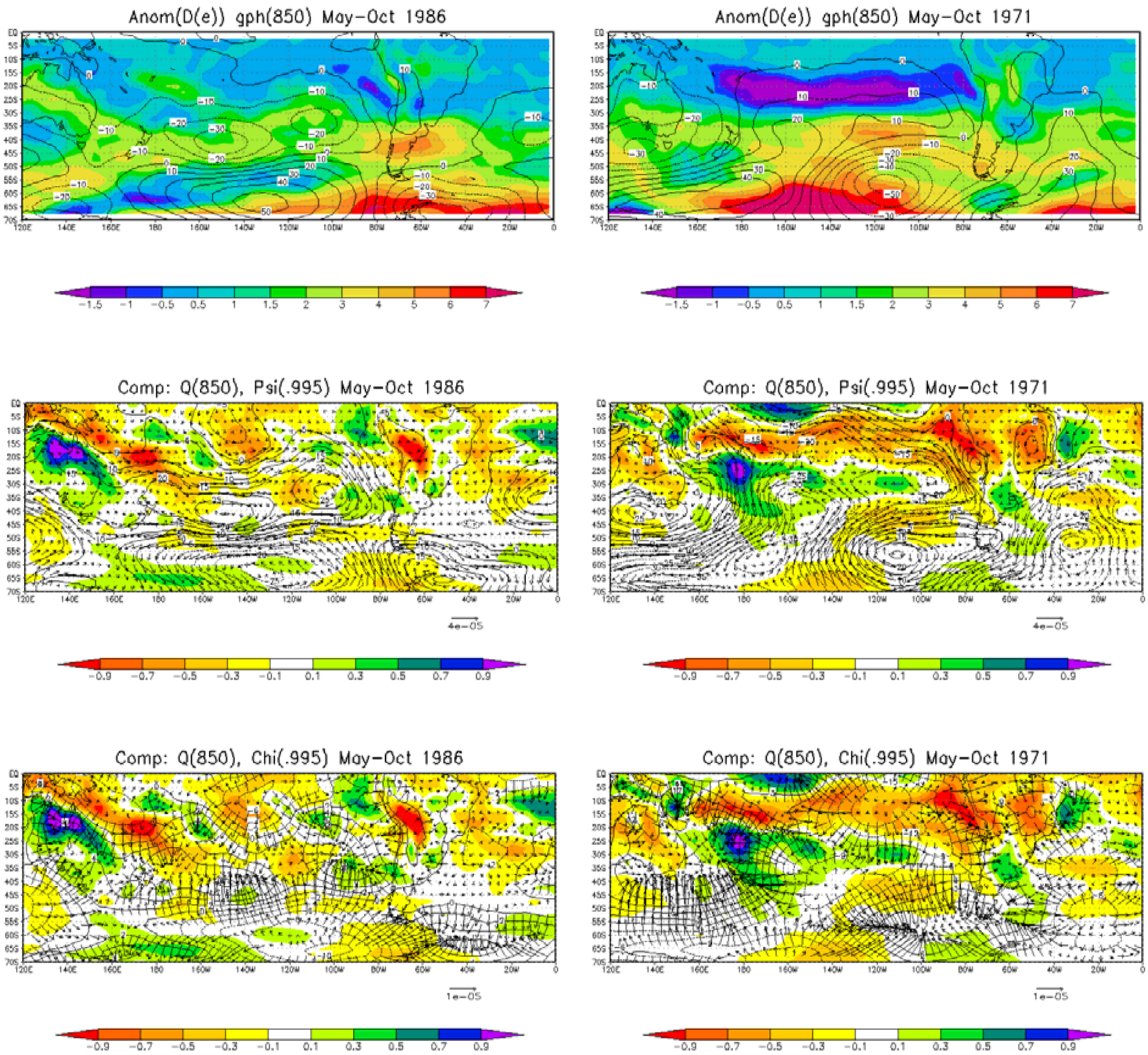

Figure 4. Seasonal average anomalies of the absolute value of 500/1000hPa thickness horizontal gradient and GPH in 850 hPa (above); Specific Humidity in 850 hPa, Stream Function and Rotational Wind Component in σ=0.995 (centre); and Specific Humidity in 850 hPa, Potential Wind and Divergent Wind Component in σ=0.995 (low); corresponding to the period May-October 1986 (left) and 1971 (right).

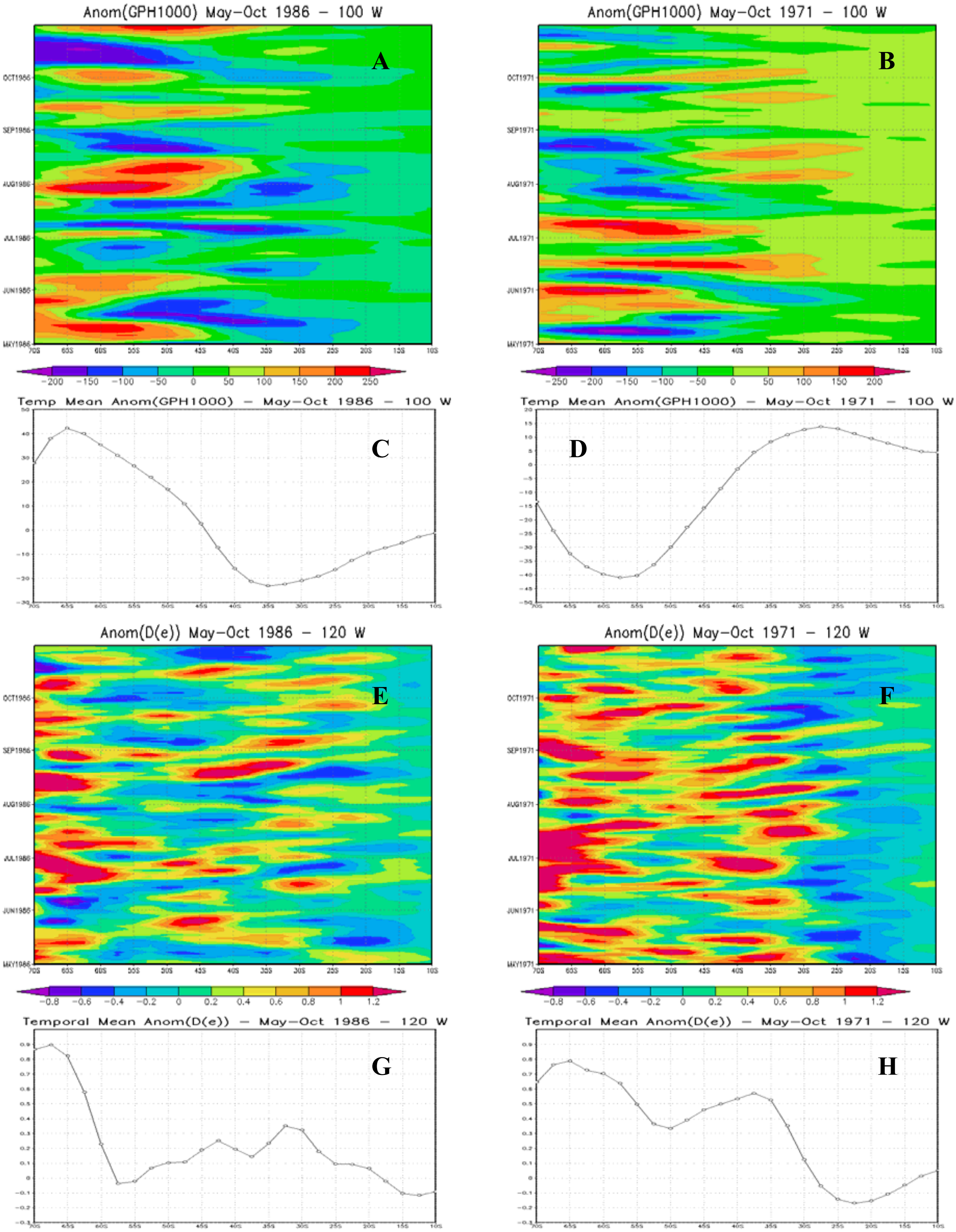

Figure 5. Hovmoller diagrams in a meridional crossection at 100°W for the daily GPH anomalies in 1000 hPa corresponding to the May–October 1986 (A) and 1971 (B) periods. Panels C and D show the temporal averages corresponding to the diagrams of the panels A and B respectively. Panels E, F, G and H are analogous to the previous ones but for the absolute values of 500/1000 hPa thickness horizontal gradient at a 120°W crossection.