MOISTURE FLUX AND CYCLONES FREQUENCY VARIABILITY OVER SOUTH AMERICA DURING INTER-EL NIÑO EVENTS

Gyrlene A. M. da Silva*, Tércio Ambrizzi*
*Department of Atmospheric Sciences, Institute of Astronomy, Geophysics and Atmospheric Sciences,
University of São Paulo, Brazil

1. INTRODUCTION

The increasing availability of moisture toward southeast South America contributes to convective instability and consequently extratropical cyclogeneses events near the east coast of the continent between 15ºS–60°S (Gan and Rao, 1994a; Sinclair, 1994, Mendes et al., 2007). Also the extratropical cyclones that are generated in South Pacific tend to form and intensify in middle latitudes, moving eastward, and reaching the continent as they mature and decay (Jones and Simmonds, 1993; Sinclair, 1995). For both cases they play an important role in transporting moisture to the poles and interacting with tropical convection.

It is important to mention that the meridional moisture transport east of the Andes and the extratropical cyclones are responsible, in part, by the precipitation variability over the subtropics of South America. Some case studies have showed that these systems present variability at the interannual time scale and, therefore, being related to El Niño/Southern Oscillation (ENSO) phenomenon, which is the first mode of influence dominating the South American summer rainfall variability (Zhou and Lau, 2001; Nogués-Peagle, 2002).

Many authors have appointed out an inter-ENSO variability on the signal (Drummond and Ambrizzi, 2003; Magaña and Ambrizzi, 2005; Silva and Ambrizzi, 2006) over the South American continent. According Magaña and Ambrizzi (2005) the inter-ENSO variability is the result of fluctuations in the phase and amplitude of the stationary Rossy waves emanating from the central/eastern Pacific. However, there is some uncertainty, on whether these changes correspond to real inter-ENSO variability via teleconnections or to internal variability of the mid-latitude circulations. Through numerical and observational data analysis Drummond and Ambrizzi (2003) studied the EN events of 1982/83, 86/87, 91/92 and 97/98, and verified that each episode has a specific Sea Surface Temperature (SST) forcing and atmospheric circulation and therefore they cause a different impact on the Americas precipitation.

Silva and Ambrizzi (2006) verified that during the strong EN of 1997/98 a low-level anomalous anticyclonic circulation over the central part of Brazil enhanced the wind in the nucleus of the SALLJ and displaced the jet to the Northern Argentina and South of Brazil. On the other hand, during the weak EN of 2002/03 the SALLJ was less intense and displaced towards the Southeast of Brazil.

The main objective of this paper is to describe the dynamical process related to the impact of the inter-El Niño variability on the moisture transport exchange between the Amazon and La Plata Basin and the role of the extratropical cyclones on it. For instance an automatic tracking scheme like the ones used in previous studies (Murray and Simmonds, 1991a,b; Pezza and Ambrizzi, 2003, 2005; Beu and Ambrizzi, 2006) can be applied to find and track lows.

The dataset used and the methodology are described in section 2. In section 3 the SST anomalies and analysis of the water vapor transport over the South America for ENSO extremes are examined. Section 4 shows the track maps overlapping all synoptic trajectories, the density and central pressure anomalies made for inter-EN events. Section 5 provides a summary and concluding comments.

2. DATA AND METHODOLOGY

2.1 Data

The gridded precipitation data were obtained from Liebmann and Allured (2005) on 1º grid for 1977 to 2000 period, where December represents the initial year (0) and February the following year (1). The monthly reanalysis from National Centers for Environmental Production (NCEP)–National Center for Atmospheric Research (NCAR) reanalysis (Kalnay *et al*., 1996) is used for the same period in a 2.5º X 2.5º latitude-longitude grid and include: horizontal wind (u,v), specific humidity from 1000 hPa up to 700 hPa, and vertical *p*-velocities (ϖ) at 500 hPa level. Monthly mean streamfunction (ψ) at 0.21 sigma level (about 200 hPa level) and SST monthly mean from Met Office Hadley Centre's (Rayner et al. 2003) in a 2.0º x 2.0º longitude-latitude grid were also used. Gridded precipitation data from Liebmann and Allured (2005) on 1º grid for the same period was used. This dataset was generated from daily precipitation observations over the South American continent based on 7900 meteorological stations. In addition, 6-hourly Sea Level Pressure (SLP) from NCEP/NCAR are used for the same period for applying the automatic scheme (Murray and Simmonds, 1991a,b) and generating the summertime extratropical cyclone tracks, density and central pressure anomalies.

Corresponding author address: Gyrlene A. M. da Silva, Department of Atmospheric Sciences, IAG/USP. Matão Street, 1226. 05508-090; e-mail: gyrlene@model.iag.usp.br

2.2 Methodology

The years of EN extremes included in this study were chosen following the same criteria of Zhou *et al.* (2001) and indicate the beginning of the episodes: strong EN events (STR_EN) – 1982/83, 1991/92, 1997/98 ; weak EN events (WEA_EN) – 1976/77, 1977/78, 1987/88, 1990/91, 1992/93, 1994/95. The precipitation and atmospheric circulation variables during DJF are computed at each grid point and are based on departures from neutral ENSO years (NEU), i.e., the differences STR_EN minus NEU and WEA_EN minus NEU. The atmospheric configuration of the flow at lower levels and its vertical moisture distribution was represented by a vertically integrated moisture flux and its divergence (1000 to 700 hPa) as in Grimm (2003).

A Student's T test (Harrison and Larkin, 1998) was applied to all composites to determine the areas of statistical significance. The anomalies of the composites were accepted with the confidence level of 95%.

An automatic scheme was used to identify cyclonic centers near the surface. The objective here is track and calculate the density and central pressure anomalies of extratropical cyclones focusing on the South America according to the inter-El Niño variability. The analyses are made for every 6 h because some studies suggested that the automatic scheme's performance show significant improvement in this time scale. Only cyclones with central pressure below 1010 were considered. Unfortunately, heat lows such as the Chaco Low are also identified by the scheme. However, this threshold forces the scheme to capture mainly mid- and high-latitude systems reducing the spurious tropical and orographic systems (Pezza and Ambrizzi, 2003).

Simmonds and Keay (2000a) have already shown that a large number of cyclonic systems are found between 50ºS-70°S which corresponds to a baroclinic region during all seasons. Our focus is on the cyclones behavior over the South American continent in order to explore the main features associated with EN and the differences between inter-events. The system density (SD) is defined as the number of cyclones in an area of 10^3 (deg. lat)^2, and the central pressure (PC) is the difference between the mean central pressure of the lows and the climatological mean pressure at a given location.

More details about the automatic scheme is described in Pezza and Ambrizzi (2003).

3. INTER - EL NIÑO VARIABILITY AND THE SOUTH AMERICAN CIRCULATION ANOMALIES

Figure 1 displays the rainfall anomaly composites for the El Niño extremes. For STR_EN years significant anomalies are related to the positive values in Uruguay, Northern Argentina, Paraguay, Southern Brazil, i.e., mostly of the La Plata basin, and over some parts of the southeast Brazil (Figure 1a). For WEA_EN years, positive anomalies are found in Northern Argentina and Uruguay but less intense than in Fig. 1a, and negative ones in Southern Brazil.

The SST anomalies associated with the precipitation anomalies showed in Fig. 1 provide a general view of the hemispheric forcing that may have impacted the rainfall anomalies and extratropical cyclone during the composed years (Figures not shows). During the STR_EN the positive SST anomalies over the Tropical Pacific are more equatorial confined on central eastern part of the basin with anomalies above 4.0ºC. Over the Atlantic Ocean significant and positive SST anomalies are observed near the south and southeastern coast of Brazil. The warm SST anomalies during the WEA_EN are weaker, with its nucleus displaced to the central equatorial Pacific and more meridionally elongated spreading around 20º to each hemisphere. The SST anomalies are not significant over the Atlantic.

The atmospheric circulation features associated with the SST anomalies described above are shown in Figure 2. The STR_EN 200-hPa ψ zonally asymmetric anomaly composite shows a Rossby wave train pattern spanning poleward from the central-east Equatorial Pacific to the southeastern Pacific (Figure 2a). The anticyclonic center over southeast South America is consistent with the observed wet condition in this region (Figures 1a). In WEA_EN the 200-hPa ψ anomalous pattern is weaker and with no significant values over the most part of the continent (Figure 2c).

The 500-hPa ϖ anomalies for STR_EN show ascending motion along the central-eastern Equatorial Pacific, northwestern Amazon and subtropics of South America (Figure not shown). Descending motion over the extreme north of the continent and adjacent Atlantic is observed. In WEA_EN composites there are ascending motions over the most part of the South America and a lesser pronounced descending motion over the Equatorial Pacific (Figure not shown). This is in accordance with the differences of precipitation anomalies shown in Figure 1.

In Figure 2b the composite of the vertically integrated moisture flux and divergent during STR_EN events shows that the meridional moisture transport from the tropics to the subtropics is intense where anomalous moisture divergence in the Tropical North Atlantic and Amazon regions seems to contribute to the anomalous convergence over the Northern Argentina and Southern Brazil. It is also observed a divergence flux over the Atlantic near the northeast coast of Brazil that converges over the South of Brazil. In the WEA_EN events the northeasterly moisture flux from the Tropical North Atlantic to the North and Northeast Brazil have a cyclonic curvature pattern centered at 52°W;10ºS (Figure 2d). A weak anticyclonic moisture flux pattern centered at 52ºW; 27ºS is observed in the Southern Brazil which probably contributes to the moisture convergence over Paraguay and Northern Argentina. Many authors (Berri and Inzuza, 1993; Herdies et al., 2002; Doyle and Barros, 2002; Drumond et al., 2008) have already pointed out the importance of the circulation associated to the western part of the subtropical South Atlantic high which carries water vapor from the South Atlantic subtropics towards the continent. Comparing Figures 2b and 2d it is possible to note that this contribution is more evident during STR_EN years. In addition, Figure 3b shows that on austral summer of WEA_EN years the eastern Brazilian Coast in the Atlantic Ocean and the tropical North Atlantic Ocean are the main moisture sources for the Central Brazil region and the moisture transport via SALLJ is weakened.

4. INTER - EL NIÑO VARIABILITY AND THE EXTRATROPICAL CYCLONES PATTERNS OVER SOUTH AMERICA

Figure 3 shows the total amount of austral summer cyclone tracks, SD and PC anomalies during STR_EN. Comparing Fig. 3a with those composite for WEA_EN years (Figure not shown), one can see that, in both cases there are two bands with larger number of tracks. One of then is concentrated along 20º-40ºS over Argentina and Paraguay associated to the heat lows and the other band is concentrated around the southeast of the South American continent positioned over the region that according to previous studies is favorable to cyclogeneses (Gan and Rao, 1991; Vera et al., 2002, Mendes et al., 2007). The cyclone tracks during STR_EN years are reduced when compared to the WEA_EN years and it is displaced towards high latitudes. However, it seems that the number of systems over South of Brazil is larger in the first case.

The general SD pattern anomalies observed in Fig. 3b and those composite for WEA_EN years (Figure not shown) are similar with densities typically below average over the most part of the domain. Over the Atlantic, during STR_EN events the density anomalies are slightly more negative when compared to those for WEA_EN which is in accordance with the 200-hPa ψ zonally asymmetric anomaly composites. Values below 20.5x10^3 (deg. lat)^2 over 35ºS;65ºW indicates a lesser density of systems usually originated because of the heat lows when compared to the WEA_EN events.

Although the tracks and SD show similar characteristics for both ENSO extremes, the cyclone intensities can be quite different. Fig. 4a shows two regions with positive anomalies of PC cyclone, one around the eastern part of the South Brazil and the other around the Gulf of San Matias. Many authors (Sugahara et al., 1994; Gan and Rao, 1991; Berbery and Barros, 2002; Silva et al., 2009) have suggested that the South Brazil is a cyclogeneses region located on the exit of the SALLJ and therefore there is a retro-alimentation effect (Vera, 2002) among these mechanisms. During the WEA_EN years (Fig. 4b) one can see a nucleus of positive PC anomaly over 35ºS;61ºW in agreement with the positive anomalies found in Fig. 1b suggesting that a more intense heat low can favor large intensity cyclones over this region when compared to the STR_EN years.

5. SUMARY AND CONCLUDING REMARKS

The difference between the wave amplitude and phase from strong El Niño events to weak ones induced by the tropical SST anomalies may change the moisture transport and cyclone patterns over South America, an interaction not previously discussed in the literature. The trajectories and density of the extratropical cyclones are quite similar in both El Niño extremes; however some of the differences found may be related to the physical mechanisms on the local cyclogeneses over the southeast South America.

The composites for STR_EN composites shows that there is an enhancement of the meridional moisture flux to La Plata basin from the Amazon region and equatorial Atlantic Ocean associated with the trade winds that enter in the northern equatorial part of the continent and that then are channeled southward. The moisture converges over the South Brazil near the region of PC cyclones positive anomalies may explain the intense rainfall anomalies in this case. In the WEA_EN composites, there is an cyclonic moisture flux anomaly centered at 52ºW;10º S and consequent weakening the advection of moisture from the tropics to the subtropics. Also, the extratropical cyclones shows PC above normal over the northern Argentina and Uruguay which could explain the differences in the precipitation anomalies found in these regions when compared to the STR_EN composites.

Acknowledgments
We thank Brant Liebmann and Dave Allured for providing rainfall data and the Climate Prediction Center (CPC/NCEP/NWS) for providing the reanalysis. This work was supported by Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP 01/13816-1 and 05/01804-0). TA also acknowledges the partial support from CNPq, CAPES and the CLARIS LPB project.

REFERENCES

Drumond, A.R.M. and Ambrizzi. T., 2003: Observational and numerical study of the atmospheric circulation over the Americas during extreme episodes of the Southern Oscillation. *Brazilian Journal of Meteorology*, 18(1): 1-12 [*Available in Portuguese*].

Drumond, A.R.M.; Nieto, R.; Gimeno, L.; and Ambrizzi T., 2008: A Lagrangian identification of major sources of moisture over Central Brazil and La Plata Basin. *J. Geophys. Res.*, 113, D14128, doi:10.1029/2007JD009547.

Gan, M. A. and Rao, V. B., 1991: Surface cyclogeneses over South America. *Mon. Wea. Rev.*, 119, 1293-1302.

Grimm, A.M.; Barros, V.R.; and Doyle, M.E., 2000: Climate variability in Southern South America associated with El Niño and La Niña events. *Journal of Climat*e, 13, 35-58.

Grimm, A.M., 2003: The El Niño impact on the summer monsoon in Brazil: Regional processes versus remote influences. *Journal of Climat*e, 16, 263–280.

Harrison, D.E. and Larkin, N.K., 1998: El Niño-Southern Oscillation sea surface temperature and wind anomalies, 1946-1993. *Rev.Geophys*, 36(3), 353-399.

Herdies, D. L.; da Silva, A.; Silva Dias, M. A.; and Nieto-Ferreira, R., 2002: Moisture budget of the bimodal pattern of the summer circulation over South America, *J. Geophys. Res*., 107(D20), 8075, doi:10.1029/2001JD000997.

Kalnay, E.; Kanamitsu, M.; Kistler, R.; Collins, W.; Deaven, D.; Gandin, L.; Iredell, M.; Saha, S.; White, G.; Woollen, J.; Zhu, Y.; Chelliah, M.; Ebisuzaki, W.; Higgins, W.; Janoviak, J.; Mo, K.C.; Ropelewski, C.; Wang, J.; Leetmaa, A.; Reynolds, R.; Roy, J.; and Joseph, D., 1996: The NCEP/NCAR 40-year Reanalysis *Project. Bulletin of the American Meteorological Society* 77(3): 437-471.

Jones, D.A. and Simmonds, I., 1993: A climatology of Southern Hemisphere extratropical cyclones. *Climate Dynam*., 9, 131–145.

Liebmann, B. and Allured, D., 2005: Daily precipitation grids for South America. *B. Am. Meteorol. Soc*., 86, 1567-1570.

Magaña, V. and Ambrizzi, T., 2005: Dynamics of subtropical vertical motions over the Americas during El Niño boreal winters. *Atmósfera,* 18(4), 211-233.

Mendes, D., Souza, E. P, Trigo, I. F, and Miranda, P.M.A., 2007: On precursors of South American cyclogeneses, Tellus A, 59(1), 114-121, doi:10.1111/j.1600-0870.2006.00215.x

Mo, K.C. and Paegle, J.N., 2001: The Pacific-South American modes and their downstream effects. *Int. J. Climatol.*, 21, 1211–1229.

Murray, R. J. and I. Simmonds, 1991: A numerical scheme for tracking cyclone centers from digital data. Part I: Development and operation of the scheme. *Aust. Meteor. Mag*., 39, 155-166.

Nogués-Peagle, J. and Mo, K.C. 2002: Linkages between summer rainfall variability over South America and sea surface temperature anomalies. *Journal of Climate,* 15(12), 1389–1407.

Pezza, A. B. and Ambrizzi, T., 2003: Variability of Southern Hemisphere Cyclone and Anticyclone Behavior: Further Analysis. *J. Climate*, 16 (7), 1075-1083.

Rao, .V.B., Hada, K., 1990: Characteristics of rainfall over Brazil: Annual variations and connections with Southern Oscillation. *Theoretical and Applied Climatology,* 42, 81-91.

Rayner, N. A.; Parker, D. E.; Horton, E. B.; Folland, C. K.; Alexander, L. V.; Rowell, D. P.; Kent, E. C.; Kaplan, A., 2003: Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century. *J. Geophys. Res,* 108, D14, 4407 10.1029/2002JD002670.

Sinclair, M. R., 1997: Objective Identification of Cyclones and Their Circulation Intensity, and Climatology. *Weather and Forecasting*, 12, 595-612.

Sinclair, M. R.; Renwick, J. A.; Kidson, J. W., 1997: Low-Frequency Variability of Southern Hemisphere Sea Level Pressure and Weather System Activity. *Mon. Wea. Rev*., 125, 2531-2543.

Silva, G.A.M. and Ambrizzi, T., 2006: Inter-El Niño variability and its impact on the South American low-level jet east of the Andes during austral summer – two case studies. *Advances in Geosciences* , 6, 283–287,, SRef-ID: 1680-7359/adgeo/2006-6-283

Silva, G. A.M.; Ambrizzi, T.; and Marengo, J. A., 2009: Observational evidences on the modulation of the South American Low Level Jet east of the Andes according the ENSO variability. *Annales Geophys.*, In review.

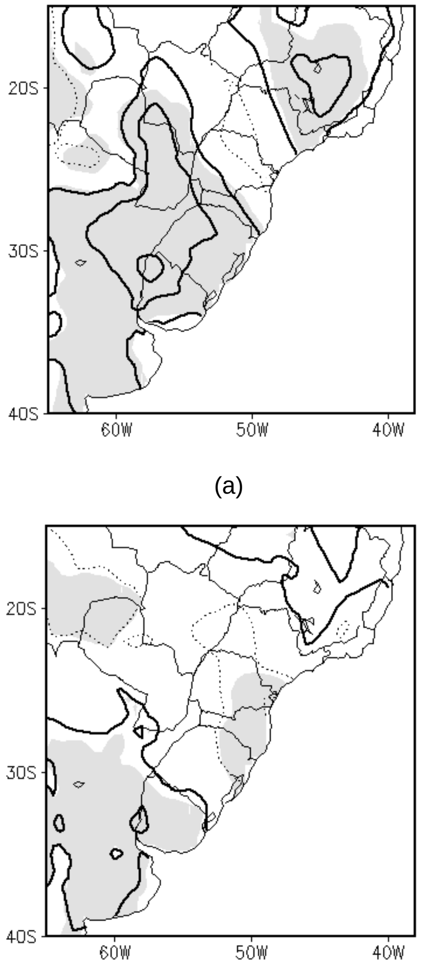
Silvestri, G., 2004: El Niño signal variability in the precipitation over southeastern South America during austral summer. *Geophys Res Lett,* 31, L18206, doi: 10.1029=2004GL020590.

Sugahara, S.; Rocha, R.P.; and Rodrigues, M.L., 1994: Condições atmosféricas de grande escala associadas a jato de baixos níveis na América do Sul (in Portuguese) . I*n: VIII Brazilian Congress of Meteorology*, 2, 573-577.

Vera, C.; Vigliarolo, P.K.; and Berbery, E.H., 2002: Cold season synoptic scale waves over subtropical South America. *Mon. Weather Rev*., 130, 684-699.

Zhou, J., Lau, K.M.; 2001: Principal modes of interannual and decadal variability of summer rainfall over South America. *International Journal of Climatology* 21: 1623–1644. DOI: 10.1002/joc.700.

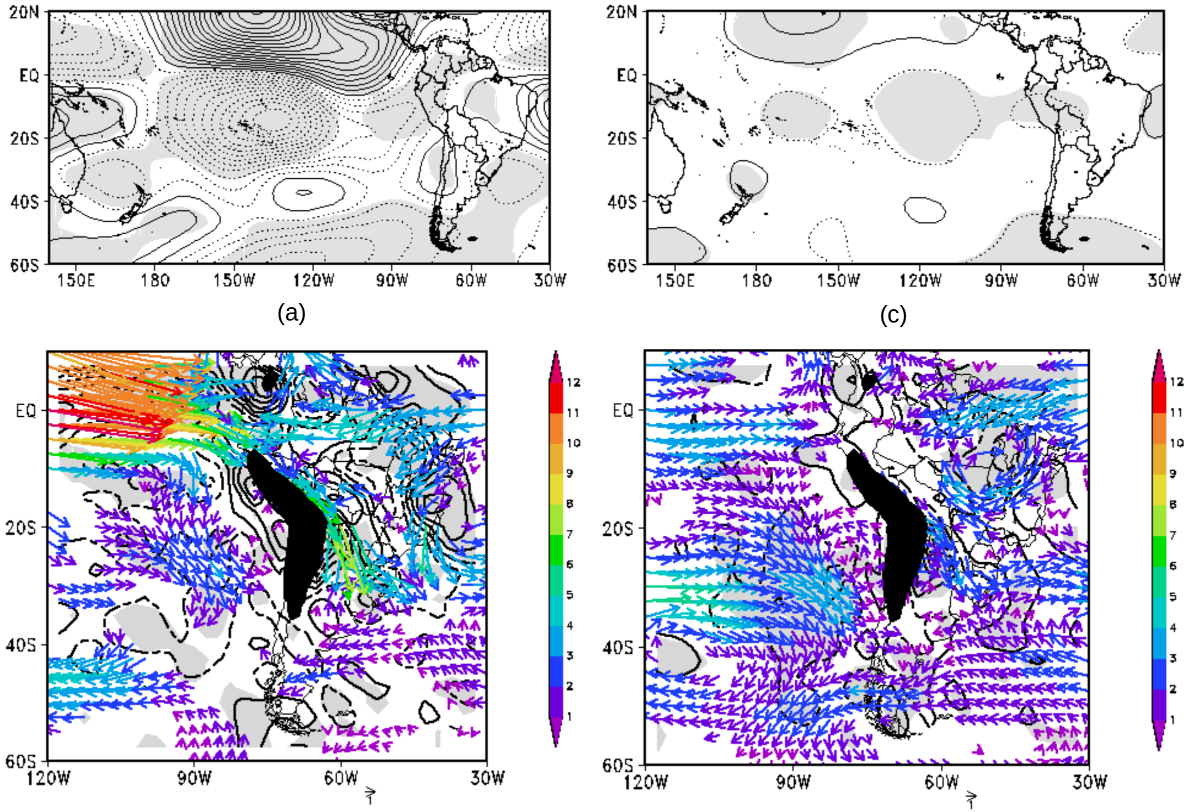
Zhou, Y.P.; Higgins, R.W.; and Kim, H-K., 2001: Relationships between El Niño– Southern Oscillation and the Arctic Oscillation: A Climate– Weather Link. *NCEP/Climate Prediction Center Atlas* 8. [Available online at http://www.cpc.ncep.noaa.gov/products/outreach/atlas.html]



(a)

(b)

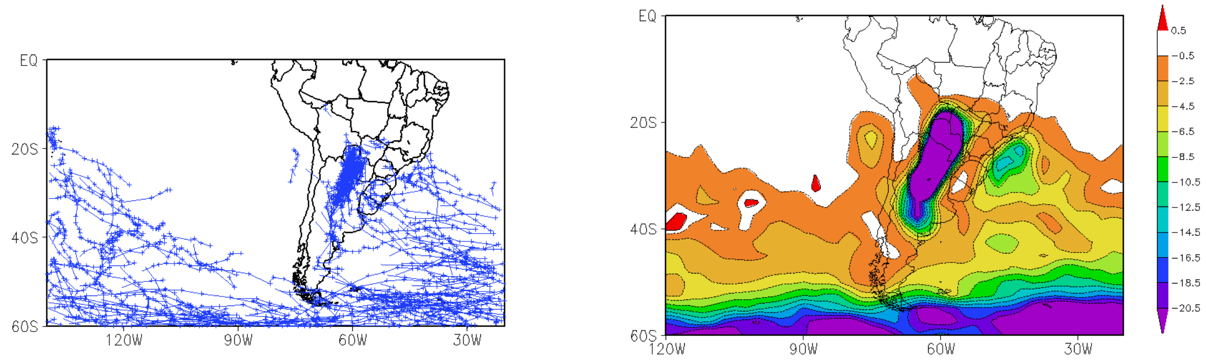
Figure 1: Precipitation anomaly during austral summer for: (a) STR_EN; (b) WEA_EN years. Contour interval is 1 mm.day^{-1}. Negative contours are dotted and the zero contours are omitted. Areas where the anomalies are statistically significant at the 95% level are shaded in gray.



(a) (c)

(b) (d)

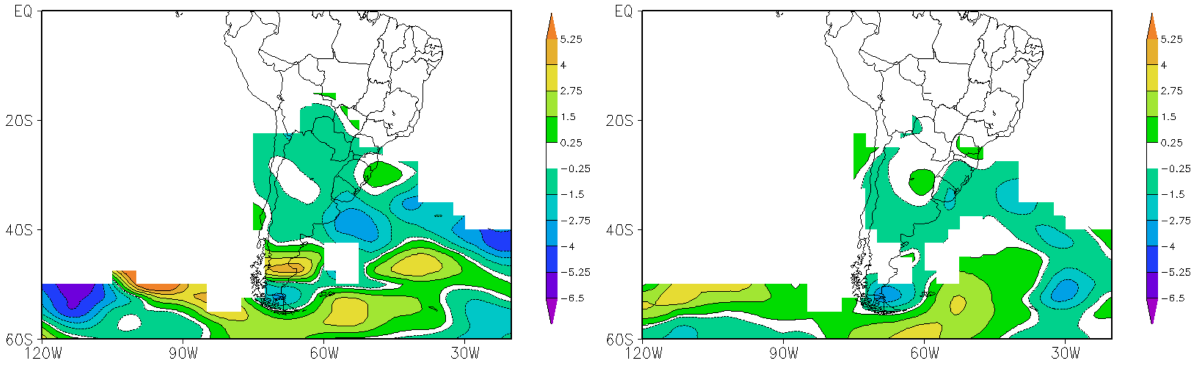
Figure 2: Anomaly composites during austral summer from 1977-2000. On the left panel (a) zonally assimetric 200-hPa ψ; (c) vertically integrated moisture flux and associated divergence associated for STR_EN years; on the right panel the same as left panel but for WEA_EN years. Contour interval is 4 $m^2.s^{-1}$, 1 $mm.day^{-1}$ and the negative contours are dotted. The shaded areas indicate statistically significant anomalies at the confidence level of 95%



(a)

(b)

Figure 3: Cyclones tracks (a) and System Density (b) during austral summer from 1977-2000 for STR_EN years. Tracks had to be at least 24 h long to be considered. See text for more details. Contour interval is 2.10^3 (deg. lat)$^{2.}$ hPa.



(a)

(b)

Figure 4: Central Pressure of the extratropical cyclones during austral summer from 1977-2000 for STR_EN (a) and WEA_EN (b) years . Contour interval is 1.25 hPa.