Climatology of Low-Level Jet East of the Andes as derived from the NCEP reanalyses

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Abstract

A climatology of the Low Level Jet East of the Andes (LLJ) is developed using the 1950-2000 circulation and moisture fields from the NCEP reanalyses. Upper and low-level circulation fields were determined for mean summer and wintertime, and for composites of LLJ events during those seasons. The Bonner criterion 1 was applied for circulation fields for sites en central Bolivia (assumed as the core region), and in northern Paraguay (exit region) to determine the spatial and temporal characteristics of the LLJ. On the circulation characteristics, composites of summertime LLJs shows the enhanced meridional moisture transport coming from tropical South America. The upper level circulation shows a wave train emanating from the West Pacific propagating towards South America. The intensification of the LLJ obeys to the establishment of an upper-level ridge over southern Brazil and a trough over most of Argentina. Regarding the time variability, LLJ seems to occur all year long, with the LLJ bringing tropical air masses from the Amazon into southern Brazil-Northern Argentina more frequent in summer, and the LLJ that brings subtropical air from the Subtropical Atlantic High more frequent during winter. The diurnal cycle shows that LLJs are more frequent and intense between 06 and 12 (01 and 07 LST) for the warm season in the core region of the jet, while at the exit region the maximum is detected between 00 and 06 Z. during the cold season. This is somewhat similar to the summertime LLJs in the US Great Plains. At interannual time scales, even though there is a weak tendency for stronger/more frequent LLJ episodes during El Niño year 1998, we cannot affirm with large degree of certainty that there is any relationship between the occurrence of El Niño events and the number and/or intensity of LLJ episodes.

1. Introduction

The LLJ is a wind maximum situated within the lowest 1 or 2 km, which sometimes exhibits a horizontal extent of sub synoptic dimensions and often has strong diurnal oscillations. It represents a relevant feature of the warm season low-level circulation, and represents a poleward transport of warm and moist air concentrated in a relatively narrow region, with strong wind speeds at low-levels, carrying moisture from the Amazon basin towards the agriculturally productive regions of southern Brazil and northern Argentina. The first climatology of LLJ was for the United States by Bonner (1968) using 2 years of rawinsonde data for 47 stations. He found that the LLJ occurred most frequently over the Great Plains east of the Rocky Mountains, with significant diurnal and seasonal variations (more LLJs episodes in early morning soundings that in the afternoon soundings, and more frequent in August and September). This climatology was later updated by Whiteman et al. (1997). Bonner's work has been widely referenced (Bonner and Paegle 1970, Whiteman et al. 1997, Paegle 1998) to identify LLJ in the Americas, and even though his method is based on observations, his methodology also has been applied to NCEP reanalyses for studies of LLJ events during the warm season of 1998 and 1999 (Douglas et al. 1999, Saulo et al. 2000, Marengo et al. 2002).

The South American LLJ exhibits important observational features that still remain unexplored, especially its time variability. The available upper-air observational network in South America seems to be unsuitable to capture the occurrence of the LLJ horizontal extension and intensity, since no operational radiosonde is launched regularly available near the core region of the jet. In this study, we introduce a climatology of LLJ episodes during the period 1950-2000. We focus on the diurnal, seasonal and interannual variability of LLJ activity east of the Andes, and on the atmospheric circulation features that accompany strong LLJ cases. We adopt the LLJ definition based on surface wind and wind speed profile and stratification (Bonner Criterion 1).

2. Data and methodology

Daily circulation and moisture fields from surface to 200 hPa levels at 0000, 0600, 1200 and 1800 Z from the NCEP global reanalysis on the 2.5°x2.5°latitude/longitude grid (Kalnay et al. 1996) have been used in this study. The analysis is made at the regional level, as well as over grid boxes nearest to locations presumably located along the main stream of the LLJ in Bolivia, Paraguay and southern Brazil. Based on previous studies (Marengo et al. 2002, Douglas et al. 1999), we select Santa Cruz (Bolivia) as a location in a region where the core of the jet is located, and Mariscal Estigarribia (Northern Paraguay) as representative of the exit region of the jet. The core region tends to experience the strongest low level winds, while the exit region experiences the intense convective activity. The analysis is made during the spring-warm season (November-February) and the autumn-cold season (May-August) seasons, both for the whole season and for composites of periods with LLJ. The Bonner criterion 1 is applied to the NCEP reanalyses for grid points nearest to stations in Bolivia (Cobija, Santa Cruz), Paraguay (Mariscal Estigarribia) and near by Foz de Iguaçu. The conditions that must be satisfied to identify a LLJ are: (a) $v > u$: Meridional winds more predominant that zonal winds; (b) $v < 0$: Northerly flow, (c) v (925 hPa) >= 12m/s (Near surface winds equal or larger than 12 m/s); (d) v (925 hPa)-v (700 hPa) >= 6m/s per km (Wind speed above the jet must decrease at a rate of at least 6 m/s per km. Also, the level of maximum wind should be at or below the 3 km level).

3. Low Level Jet Characteristics and variability

3.1 Geographical Distribution of LLJ wind and moisture fields during summer and winter

Regarding the low level circulation, Fig. 1 shows the low level circulation during summer and winter mean and for LLJ composite. The main features of the circulation in South America have been described in previous papers (Seluchi and Marengo 2000 and others). Fig. 1a-c shows the low-level moisture flow and the meridional moisture transport for the mean November-February, and the mean for the days with LLJ only during the same season detected in Santa Cruz. The season mean shows the strong Northeast trades into the Amazon basin and the deflection of the wind to the east of the Andes, with the strong low level flow which is strongest at this season of the year. The composite for LLJ events show the intensification of the low level flow east of the Andes and the enhanced meridional moisture transport coming from tropical South America, almost 5 times stronger than that of the mean summer season. During winter (Fig. 1b-d) the mean seasonal flows shows the weakening of the northeast trades into the Amazonia and of the northwesterly flow parallel to the Andes, and an intensification of northwesterly flow associated with the winds of the Subtropical Atlantic high, that at this time of the year is intensified and northward displaced, intensifying its effect into subtropical South

America. In the core region, composite of LLJ during summer shows the speed of the northerly flow reaching 12 m/s, with maximum between 850-900 hPa and extending up to 50 W. In comparison, at the exit region, the summertime mean shows weak flow from the northwest (along the eastern side of the Andes) with an intense flux from the northeast, coming from the subtropical Atlantic. The LLJ episodes identified during summer or winter were detected using the Bonner criterion 1, and this criterion does not discriminate on the type of air mass flowing along the main stream of the jet.

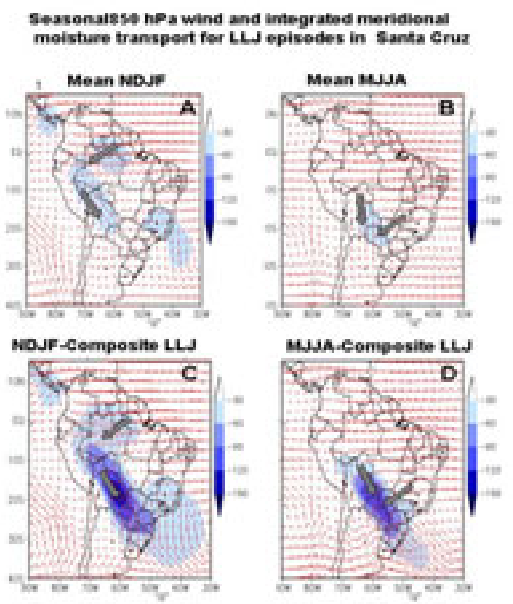

Fig. 1. Low-level circulation fields for the warm (NDJF) and the cold (MJJA) seasons, for the season mean and the composite for LLJ in Santa Cruz

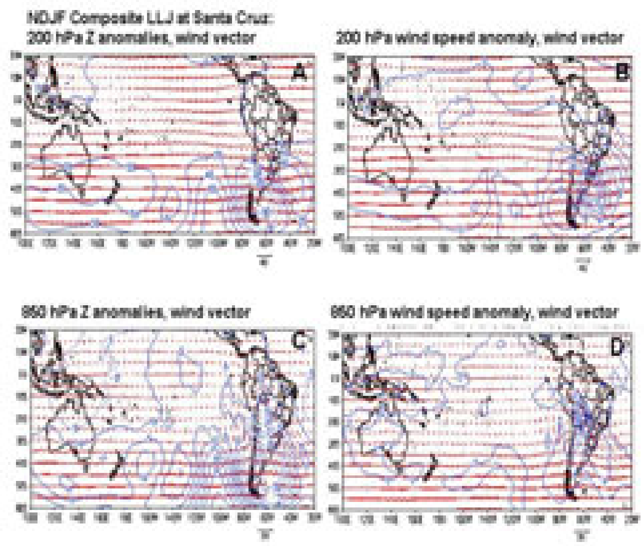

Fig. 2. Upper and lower level circulation field anomalies for a composite of LLJ during the warm season (NDJF), for episodes detected at Santa Cruz.

3.2 Circulation features associated to the presence of LLJ

The composites of circulation for cases with LLJ in Santa Cruz for summer and winter (Fig. 2a, b) show an anomalous upper-level trough (ridge) over southern south America (southern Brazil), embedded on a wave pattern that emanates from the western Pacific Ocean nearby Australia-New Zealand. An upper-level cyclonic perturbation is located over southern Argentina south of 30 S, while an anticyclonic perturbation is found over southern Brazil off the Atlantic coast. It has been shown by Liebmann et al. (1999) and Nogues-Paegle and Mo (1997), for the wave train linked to the SACZ that the cyclonic perturbation is located south of the maximum convection region, and if we apply the same reasoning in here, we find the maximum convection over southern Brazil. The wave pattern in Fig. 2a, b shows some resemblance with that related to the SACZ activity from Liebmann et al. (1999) for they day zero (day with strongest SACZ), with the difference that the ridge is located shifted to the northeast and the intense convection is located over southeastern Brazil around 20 S. Near surface (Fig. 2c, d), the 850 hPa circulation shows anomalous low-level northwesterly flow extends from northern Bolivia to southern brazil and Uruguay, which would be consistent with intense convective activity and above normal rainfall over southern Brazil, northeast Argentina and Uruguay. The intensification of a low-level trough extending from southern Argentina towards the northwest along the eastern side of the Andes is an indicator of the intensified LLJ. This shows a coherent pattern of tropospheric anomalies consistent with the approach of cold fronts, where the intense LLJ seem to lead the penetration of cold fronts that produce rainfall over the region of southern Brazil, northeast Argentina and Uruguay, while to the North of these regions rainfall is diminished.

3.3 T*ime variability*

The annual cycle of number of observations with LLJ in locations in Bolivia along the core of the jet, and in Paraguay-southern Brazil at the exit region of the jet, is shown in Fig. 3. For the region along the core, the frequency of observations showing LLJ is larger during the austral summer-autumn period (November-March), especially between Santa Cruz and Robore, and with very few episodes during winter. At the exit region, from Mariscal Estigarribia to Foz de Iguaçu, the frequency of observations showing LLJ is larger than on the core region all year long, and this number is even larger during winter as compared to summer.

Regarding the diurnal cycle, Fig. 4 shows large diurnal variability of the frequency of observations with LLJ both along the core and at the exit region of the jet, and being more pronounced at the exit region. In summer, all stations show larger number of observations with LLJ around 06Z (~01 LST), while at the exit region more observations showing LLJ are present at 12 Z (~07 LST). At Santa Cruz, the intensity of the LLJ winds can reach up to 16 m/s, especially around 12Z during. January-April, while during winter the relatively fewer LLJ episodes can also reach maximum of 14-16 m/s, with the maximum speeds between 00 and 06 Z. At the exit region of the LLJ nearby Mariscal Estigarribia, the more frequent episodes of LLJ during winter reach maximum of near 18 m/s between 00 and 06 Z, while the relatively fewer LLJ episodes during summer reach lower speeds (14 m/s) with maximum between 12 and 18Z. Considering both frequency and intensity, at the core region of the jet in Santa Cruz, during summer more frequent and stronger winds from the LLJ are observed around ~06 Z, while ate the exit region the more frequent and stronger LLJ are observed at ~12Z. In winter, the fewer LLJ observed at the core region shown largest intensity ~06 Z while at the exit region the more frequent and intense LLJ occur at 12 Z. In comparison to LLJ in the US, the LLJ over the northern Gulf of California is present all times, but weaker during the late afternoon and early evening hours (Douglas et al. 1998), while the US Great Plains LLJ reaches maximum speeds at early morning (02 LST).

The interannual variability of frequency and intensity of LLJ episodes during 1950-2000 are shown Fig 5. For Santa Cruz during LLJ during the warm season, and for Mariscal Estigarribia during the cold season. The figures do not suggest a clear signal between the occurrence of El Niño or La Niña and the number and the intensity of LLJ in both sites. For instance, in Santa Cruz, the strong El Nino 1983 featured 13 LLJ, while the equally strong El Niño 1998 experienced 29 LLJ. The strong La Niña event of 1989 showed 29 LLJ, while the cold event of 1999 featured only 7 LLJ. Other El Nino events such as 1972, 1976, 1987 and 1992-94 or La Niña events such as 1985 and 1996 do not show a clear signal of more or less frequent LLJ during El Nino or La Nina. The intensity of the winds, based on the average between 06-12Z shows that the strongest LLJ were observed during 1997-98 while the episodes during the middle 1980’s and early 1990’s were relatively weaker.

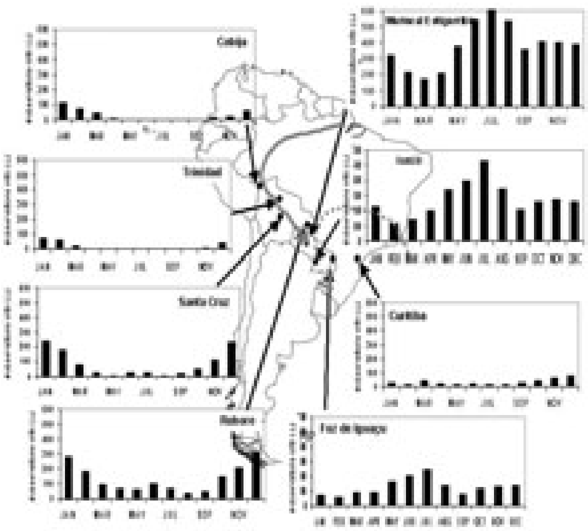

Fig. 3. Annual cycle of number of observations showing LLJ east of the Andes. Stations are shown by dots at the core and the exit region of the jet. Grey full arrow shows the trajectory of tropical moist air coming from Amazonia, and gray broken arrow shows the trajectory of subtropical air from the Sub tropical Atlantic high.

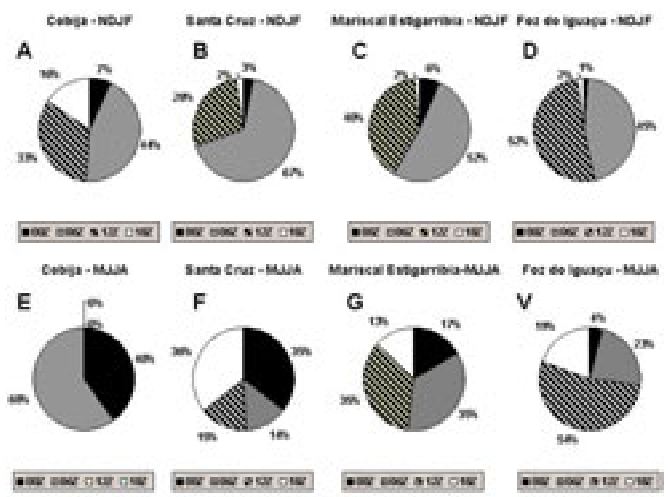

Fig. 8. Mean diurnal cycle of number of observations showing LLJ for a composite of LLJ during the warm season (NDJF) and cold season (MMJA), for stations nearby the core of the jet (Cobija, Santa Cruz) and the exit region of the jet (Mariscal Estigarribia, Foz de Iguaçu).

Marengo et al. (2002) have shown that the observed numbers of LLJ at Santa Cruz during 1998 and 1999 were 21 and 12, while the number derived from NCEP reanalyses was 29 and 7 respectively. Thus, both reanalyses and observations suggest less episodes of LLJ in 1999 as compared to 1998. Regarding the intensity of the wind speed, show that there does not seem to be any indication of any unidirectional trend in the wind speed, with the exception on a slightly negative trend on the wind speed at 00 Z during summertime observations at Santa Cruz (not shown). In Mariscal Estigarribia, the cold season LLJs do not show a consistent signal due to El Niño.

4. Discussions and conclusions

Analysis of the 1950-2000 4-times-a-day NCEP reanalyses on the region east of the Andes between Bolivia and Southern Brazil have provided a detailed climatological description of LLJ characteristics at the core and exit regions. The surface and upper level circulation associated with the composites of LLJs during summer shows the intensification of the typical mean summertime circulation features, specifically the low level flow east of the Andes and the enhanced meridional moisture transport coming from tropical South America. The upper level circulation shows a wave train emanating from the West Pacific nearby Australia-New Zealand, and propagating towards South American and one reaching the southern tip of this continent, it moves to the northeast. The intensification of the LLJ over Santa Cruz obeys to the establishment of an upper-level ridge over southern Brazil and a trough over most of Argentina, with pattern reaching somewhat larger amplitudes for LLJ detected in northern Paraguay.

Our LLJ climatology shows large frequency of LLJ at the core region in Santa Cruz during the warm season, while at the exit region the largest frequencies are found between the cold season and spring. At the exit region, fewer LLJ episodes have been identified during summer, while episodes that may bring air mass from Amazonia into Paraguay-Northern Brazil can happen also in winter, even though with very low frequency. LLJ episodes are detected all year long, with 75% of the cases detected during November-February at the core region near by Santa Cruz, and 25% occurring mostly during spring and autumn. At the exit region, 45% of the cases were detected during May-August, 29% during November-December, and 26% during spring. This indicates that at the core region, the LLJ more frequent during the warm season, while at the exit region, the jet are more frequent during the cold season and during spring. During the warm season, the height of the core of the LLJ east of the Andes (~12 m/s) is ~850 hPa at 62 W, with a shallow and relatively weaker (~4 m/s) second jet nearby the Brazilian Planalto (~40 W). At the exit region, the LLJ east of the Andes, some episodes of LLJ are detected during the warm season, even though the axis of them is located eastward to the Andes (~58 W) are they are less frequent that in Santa Cruz.

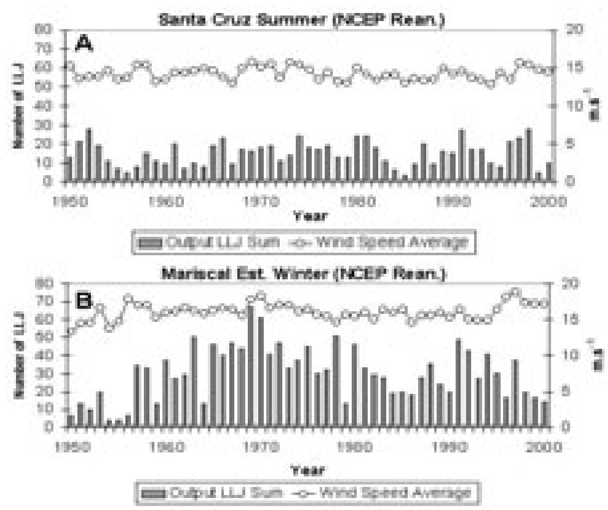

Fig.10. Interannual variability of the number of observations showing LLJ and the mean wind speed of a composite of LLJ during (a) Warm season NDJF in Santa Cruz, and (b) cold season MJJA in Mariscal Estigarribia. At Santa Cruz, the wind represents the average of 06 and 12 Z, while at Mariscal Estigarribia the average is for 00 and 06 Z.

The diurnal cycle shows that LLJs are more frequent and intense between 06 and 12 (01 and 07 LST) for the warm season in the core region of the jet, while at the exit region the maximum is detected between 00 and 06 Z. during the cold season. This is somewhat similar to the summertime LLJs in the US Great Plains, that exhibit wind speed maximum at around 02 LST (based on soundings).

At interannual time scales, even though there is a weak tendency for fewer and weaker LLJ episodes, we cannot affirm with large degree of certainty that there is any relationship between the occurrence of El Niño events and the number and/or intensity of LLJ episodes.

Observational studies and few regional model experiments have shown more LLJ episodes during 1998 (El Niño) as compared to 1999 (La Niña), but this tendency can no be corroborated for other El Niño or La Niña episodes.

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