Variability of the South American Low Level Jet (SALLJ) in Various Time and Spatial Scales

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Variability of the structure and spatial extension of the SALLJ is studies using a combination of various data sets (global reanalyses, PACS-SONET observations, OLR) and the data generated during the SALLJEX field experiment during the austral summer of 2003.

On the circulation characteristics, SALLJ composites during the warm season show the enhanced low-level meridional moisture transport coming from equatorial South America as well as an upper level wave train emanating from the West Pacific propagating towards South America. The intensification of the warm season SALLJ obeys to the establishment of an upper-level ridge over southern Brazil and a trough over most of Argentina. The circulation anomalies at upper and lower levels suggest that the intensification of the SALLJ would lead to an intensification of the South Atlantic Convergence Zone SACZ later on, and to a penetration of cold fronts with an area of enhanced convection ahead at the exit region of the SALLJ.

Regarding the time variability, SALLJ seems to occur all year long, with the SALLJs bringing tropical moist air masses from the Amazon into southern Brazil-Northern Argentina more frequent in the warm season, and the SALLJs bringing tropical maritime air less humid than the tropical air masses coming from the Subtropical Atlantic High more frequent during the cold season. SALLJs are detected mostly during the warm season to the North of ~20S, while to the south the SALLJs seem to occur all year long. The diurnal cycle shows that SALLJs are more frequent and intense between 06 and 12 Z for the warm season north of 20 S, while at the region downstream the maximum is detected between 00 and 06 Z. during the cold season. At interannual time scales, even though there is a weak tendency for stronger and more frequent warm season SALLJ episodes in years with anomalously warm surface waters in the tropical Pacific, we cannot affirm with large degree of certainty that there is a strong relationship between the occurrence of El Niño events and the number and/or intensity of SALLJ episodes. However, the El Nino 1998 featured more frequent and intense warm season jet episodes than during La Nina 1999, and this has been demonstrated by the reanalyses, the available PACS-SONET upper-air observations and by other studies using independent data sets and regional modeling.

[0000000171] - VARIABILITY OF THE SOUTH AMERICAN LOW LEVEL EAST OF THE ANDES (SALLJ) IN VARIOUS TIME SCALES

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RESUMO O ciclo diurno do SALLJ mostra que o jato é mais forte e freqüente entre as 0600 e 1200 Z durante o verão em latitudes ao norte de 20 °S, enquanto que na região de saída do jato o máximo é observado entre as 0000 e 0600 Z durante a estação de inverno. A variabilidade intrasazonal mostra associações entre a presença da SACZ, o SALLJ e a modulação de eventos extremos de chuva na região sudeste do Brasil. Aparentemente, o SALLJ ocorre durante todo o ano, mais os jatos trazendo umidade da Amazônia para o sul do Brasil são mais intensos no verão, e os jatos trazendo ar marítimo menos úmido (não tropical) do anticiclone do Atlântico Sul sub-tropical são mais freqüentes no inverno. Na escala de tempo inter-anual, ainda que exista uma tendência de existir mais episódios de jatos em anos com temperaturas do Pacifico equatorial tropical, não existe uma evidencia forte que indique com um alto grau de certeza que existe uma forte associação entre o número e intensidade de eventos jatos e a ocorrência do El Nino. Em escalas de tempo mais longas, existe uma tendência de ter mais episódios de jatos desde meados da década de 1970's, consistente com tendências negativas de chuva no norte da Amazônia e tendências positivas de chuva no sul da Amazônia e no sul do Brasil-Norte da Argentina.

[IMPRIMIR] ARQUIVO

VARIABILITY OF THE SOUTH AMERICAN LOW LEVEL EAST OF THE ANDES (SALLJ) IN VARIOUS TIME SCALES

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RESUMO

O ciclo diurno do SALLJ mostra que o jato é mais forte e freqüente entre as 0600 e 1200 Z durante o verão em latitudes ao norte de 20 °S, enquanto que na região de saída do jato o máximo é observado entre as 0000 e 0600 Z durante a estação de inverno. A variabilidade intrasazonal mostra associações entre a presença da SACZ, o SALLJ e a modulação de eventos extremos de chuva na região sudeste do Brasil. Aparentemente, o SALLJ ocorre durante todo o ano, mais os jatos trazendo umidade da Amazônia para o sul do Brasil são mais intensos nó verão, e os jatos trazendo ar marítimo menos úmido (não tropical) do anticiclone do Atlântico Sul sub-tropical são mais freqüentes no inverno. Na escala de tempo inter-anual, ainda que exista uma tendência de existir mais episódios de jatos em anos com temperaturas do Pacifico equatorial tropical, não existe uma evidencia forte que indique com um alto grau de certeza que existe uma forte associação entre o número e intensidade de eventos jatos e a ocorrência do El Nino. Em escalas de tempo mais longas, existe uma tendência de ter mais episódios de jatos desde meados da década de 1970's, consistente com tendências negativas de chuva no norte da Amazônia e tendências positivas de chuva no sul da Amazônia e no sul do Brasil-Norte da Argentina.

ABSTRACT

The diurnal cycle shows that SALLJs are more frequent and intense between 0600 and 1200 Z for the warm season north of 20 °S, while at the region downstream the maximum is detected between 0000 and 0600 Z.

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during the cold season. The intrasesonal variability shows associations with the SACZ and modulation of extreme rainfall events in SE Brazil. Even though SALLJ seems to occur all year long, with the SALLJs bringing tropical moist air masses from the Amazon into southern Brazil-Northern Argentina more frequent in the warm season, and the SALLJs bringing tropical maritime air less humid than the tropical air masses coming from the Subtropical Atlantic High more frequent during the cold season. At interannual time scales, even though there is a weak tendency for stronger and more frequent warm season SALLJ episodes in years with anomalously warm surface waters in the tropical Pacific, we cannot affirm with large degree of certainty that there is a strong relationship between El Niño events and the number and/or intensity of SALLJ episodes. On longer time scales, there seems to be a tendency for more SALLJ episodes since the middle 1970's and consistent with negative rainfall trends on northern Amazonia and positive trends in Southern Amazonia and Southern Brazil-Northern Argentina.

INTRODUCTION

In South America, the LLJ east of the Andes (hereafter, referred as SALLJ) has been characterized as a narrow stream that channels the near surface flow between tropics and mid latitudes east of the mountain range. The SALLJ has been related to moisture transport from the Amazon region into the fertile lands of southern Brazil-Northern Argentina and has been identified in studies during the 1980's and 1990's, based on few rawinsonde observations for short term periods or individual case studies (Berri and Inzunza 1993, Sugahara et al 1994, Douglas et al. 1999). Recent work based on the NCEP (National Centers for Environmental Prediction) and ECMWF (European Centre for Medium Range Weather Forecast) have identified some of the circulation and moisture transport features of the low level circulation east of the Andes suggesting an active role of the SALLJ in the position and intensity of the South Atlantic Convergence Zone (SACZ) and the rainfall and convection at the exit region of the jet in Southeastern South America (Nogues-Paegle and Mo 1997, Mo and Nogues-Paegle 2001, Berbery and Barros 2002, Nogues-Paegle et al. 2002, Marengo et al. 2004).

Few upper-air observations from the Pan American Climate Studies-Sounding Network (PACS-SONET) pilot balloon network for Santa Cruz (Bolivia) since 1998 (Douglas et al. 1998, 1999, 2000), and the implementation of the LBA/TRMM field campaign during the austral summer of 1999 (Marengo et al. 2002) additional rawinsonde observations in Santa Cruz made possible the identifications of some observed features of the vertical structure and diurnal variability of the SALLJ. The SALLJ variability in time and space is relatively poorly understood because of the available limited upper-air observational network in South America east of the Andes seems to be unsuitable to capture the occurrence of the low level jet and its horizontal extension and intensity or temporal variability. Thus, the reanalyses have by necessity been taken as a reasonable approximation to the true atmospheric state over South America east of the Andes.

In this paper, we discuss the variability in time and space of the SALLJ based on NCEP reanalyses focusing on the spatial extension of the jet, as well as on the intraseasonal, seasonal, interannual and decadal time scale as well as some projection for future cimate change scenarios, and showing the spatial distribution and extension of it. The study compiles results from recent work on SALLJ.

DATA AND METHODOLOGY

Low and upper level circulation fields were derived from the 4-times a day NCEP reanalyses (Kalnay et al. 1996), with a spatial resolution is 2.5°x2.5° latitude/longitude grid, covering the 1950-2000. The annual cycle of the SALLJ is investigated and analyze composites for the warm (NDJF) and cold (MJJA) seasons. Upper-air observations from the PACS-SONET (Pan American Climate Studies – Sounding Observational Network) from pilot balloons are used for Santa Cruz (Bolvia 17 S) and Mariscal Estigarribia 23 S), for the period after 1998. More information on this network can be found in Marengo et al. (2002) and Douglas et al (1998).

To identify Low Level jet episodes, the Bonner criterion 1 was applied to the sites of Santa Cruz and Mariscal Estigarribia, and for NCEP reanalises grid boxes nearest to sites considered as located on the axis of the SALLJ (Santa Cruz in Bolivia and Mariscal Estigarribia on northern Paraguay (See Marengo et al. 2004 for details).

These are the conditions that must be met to detect a low-level jet:

a)Northerly 850 hPa winds with speeds equal or larger than 12 m /s.

b)A vertical wind shear larger or equal than 6 m/s between 850 and 700 hPa.

c)Meridional component larger than the zonal component and the meridional winds must be from the north, in order to exclude southerly wind events.

SALLJ SPATIAL VARIABILITY

Fig. 1 shows the mean low-level circulation and moisture transport fields for a SALLJ composite detected in Santa Cruz (17 S) for the warm season, and in Mariscal Estigarribia (23 S) for the cold season. The warm season SALLJ composite map shows an intensification of the circulation features of the season mean, specifically the enhanced northeast trades from the tropical North Atlantic, the low level flow east of the Andes and the enhanced meridional moisture transport coming from tropical South America, which is almost twice the mean summer season. During the warm season, the SALLJ composite shows a weakening of the northeast trade winds and moisture transport from the Amazon region and the intensification of the winds from the subtropical Atlantic high contributed to the acceleration of the SALLJ stream driving moisture directly into La Plata basin.

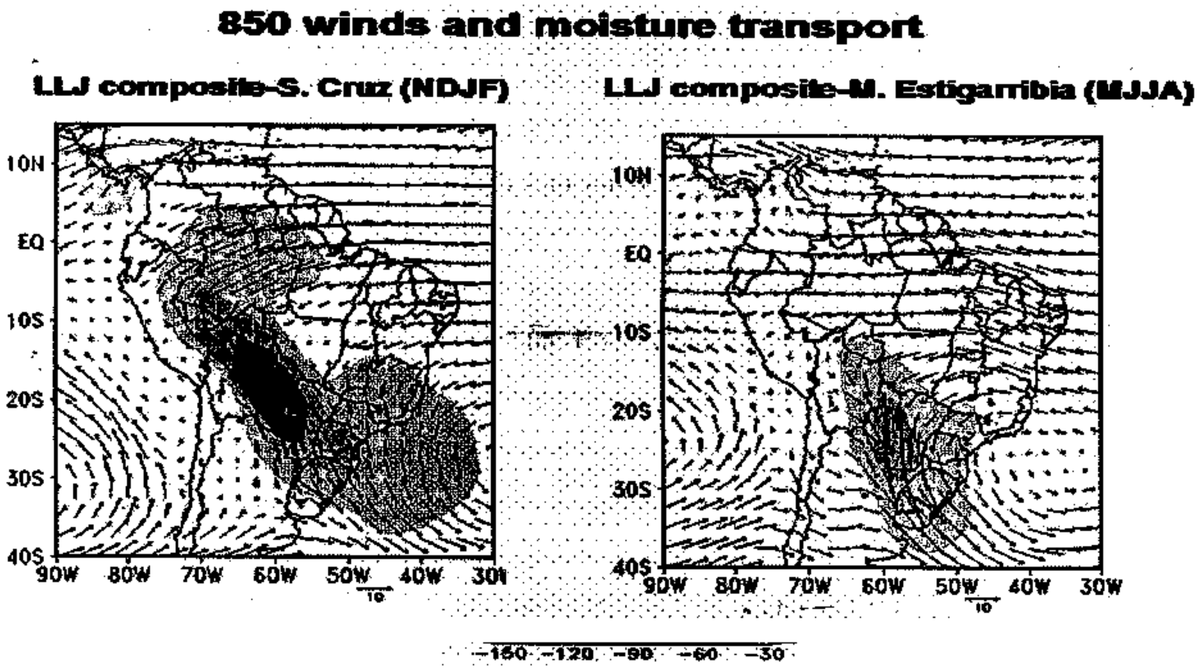

Figure 1. Low level winds (850 hPa) and meridional moisture transport flux in South America during composite oj SALLJ episodes during austral summer (NDJF) in Santa Cruz and winter (MJJA) in Mariscal Estigarribia (Marengo et al. 2004).

The cross sections meridional wind and specific humidity for the mean warm (Santa Cruz) and cold (Mariscal Estigarribia) seasons (Marengo et al. 2004) show intense southward moisture flux within the structure of the low-level jet east of the Andes, indicating higher moisture content of the warm season SALLJ as compared to relatively lower moisture content present in the cold season SALLJ.

SALLJ TEMPORAL VARIABILITY

Diurnal variability

Marengo et al. (2002, 2004) used both observations and reanalyses to show fluctuations in synoptic time scale, with the SALLJ being more frequent (almost 3 times as common) that southerly jets or cold air intrusions). Winds are stronger winds around 1100 UTC (early morning) in Bolivian stations along the core of the jet, The mean diurnal cycle from the reanalysis shows that SALLJ maximum intense occurs between 0000 and 1200 UTC (early morning), approximately at the same time as the Great Plains LLJ. The maximum winds in the surface flow downstream the SALLJ occurs at mid afternoon, at the same time of maximum of rainfall in southwest Amazonia (as related to MCCs, and not easterly moving systems as squall lines) as found in previous studies. Based on the NCEP reanalyses, Marengo et al. (2004) show that the diurnal cycle shows that SALLJs are more frequent and intense between 0600 and 1200 Z for the warm season north of 20 °S, while at the region downstream the maximum is detected between 0000 and 0600 Z. during the cold season (Fig. 2).

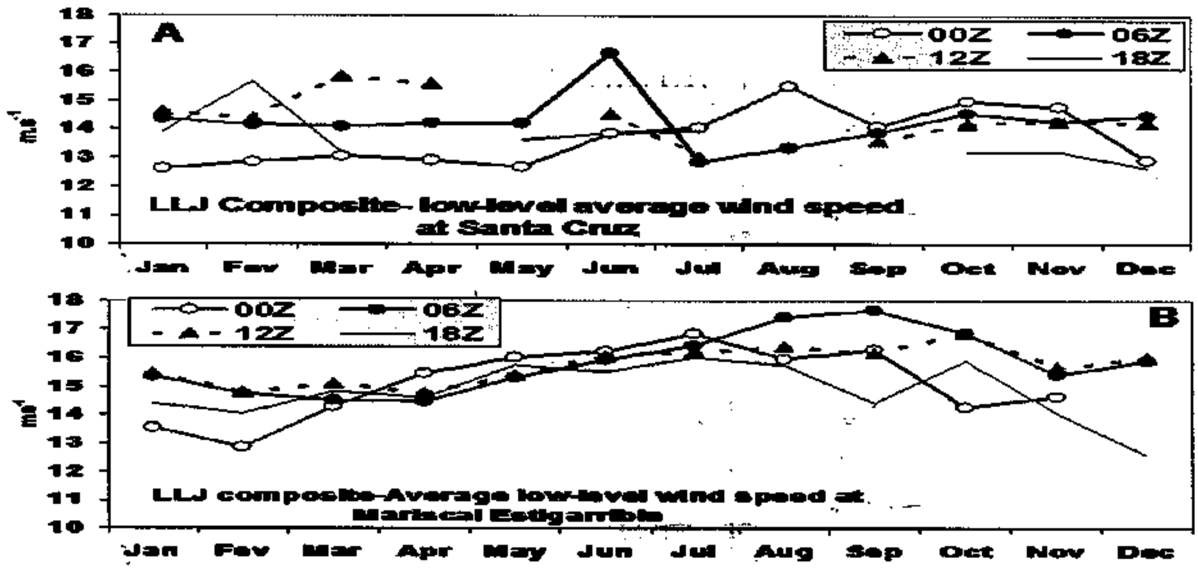

Figure 2 Annual cycle of low level wind speed at Santa Cruz (a) and Mariscal Estigarribia (b) for SALJJ composite during the 4 synoptic observation times (00, 06, 12, and 18Z).

Nicolini et al (2004) identify in various upper-air observation stations on the SALLJ region an oscillation in direction over the diurnal cycle with transitions between different time intervals instead of a regular progression. The observed behavior is consistent with a simple theoretical model that includes inertial oscillation, a subsynoptic pressure gradient related to mountain-valley differential diurnal heating/cooling and the interaction of a dominant meridional northerly component with the subsynoptic circulation. Accordingly, the mean seasonal wind vector gyre (not shown) typically behaves as described in the following paragraph. During nighttime the wind accelerates and turns anticlockwise (mostly from 03 to 12 Z consistent with an enhanced rate of rotation as the inertial oscillation is in the same direction of the two other components. After sunrise the wind direction stays almost uniform through the morning (up to 15 Z). During the afternoon the wind slows down and the sense of rotation of the wind anomaly respect to the daily mean wind vector is more variable and also more uncertain because of the reduced number of observations. At the sites near the mountains this turning is consistent with a "valley_breeze" component toward the west. Before and after sunset (mostly before 03 Z) the rate of rotation is reduced by the large-scale (dominated by a northerly flow) and subsynoptic (mountain breeze) components that oppose the inertial oscillation.

Intraseasonal variability

Recently Liebmann et al (2004) have explored the mean and intraseasonal variability of the relationship between SALLJ events and rainfall extreme events at the SALLJ exit region. Fig. 3 suggests that the percentage of daily extreme precipitation events (defined over the period 1976-1997 when daily precipitation equals at least 10% of its DJF climatology) show a good correspondence with the occurrence of the strongest SALLJ events (identified as those days on which the northwesterly NCEP reanalyses wind is at least 1.0 standard deviation above the DJF climatology).

There is mounting evidence that when moisture flux into central South America via the SALLJ is strong, SACZ convection is weak, and vice-versa (Paegle et al. 2000), and this pattern is influenced by oscillatory modes with periods both of 22-28 and 36-40 days. Thus far, however, the 30-60 day band, which is related to the Madden-Julian Oscillation MJO. Liebmann et al. (2004) explored the relationship between MJO phases and the occurrence of heavy rainfall events at the SALLJ downstream region. There is a preference for DJF extreme rainfall events to follow the MJO convective maximum by two days, while suppressed convection in the MJO region seems to precede rainfall by 26 days. Similar composites at the climatological center of the SACZ show a preference for rainfall enhancement 26 days prior to the MJO convective minimum. Those results are complementary to each other in that together they confirm the existence of a dipole in precipitation associated with the MJO between rainfall downstream of the jet and slightly southwest of the mean position of the SACZ. It might be that this dipole pattern is a consequence of the preferred phasing of synoptic waves due to variations of the planetary scale basic-state flow, which is at times associated with the MJO.

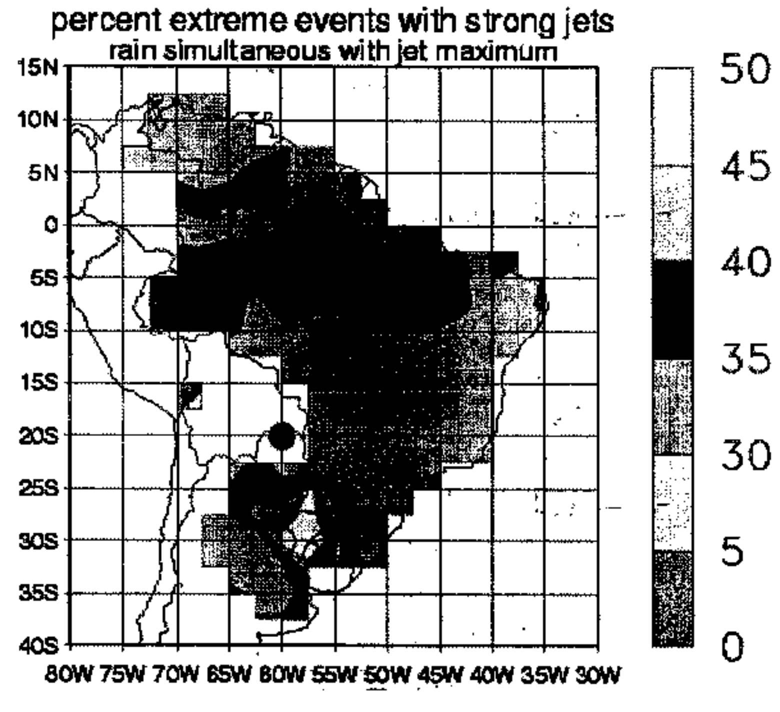

Figure 3: Percent of extreme rainfall events associated with SALLJ events at 60°W, 20°S (dark circle). Contours are at 30%, with an interval of 5%.

Seasonal variability

On the geographical distribution of SALLJ wind and moisture fields during summer and winter, Fig. 4 shows the number of cases of SALLJ events along the region of the jet to the east of the Andes, and suggests that SALLJ annual cycle depends on the latitude, the proximity to the Andes, and the circulation features during those seasons. In general SALLJ episodes can be detected during the entire year, as compared to the summertime only LLJ in the US Great Plains as identified in Berbery and Barros (2002). At lower latitudes, the seasonal cycle show that SALLJ occurrences peak during warm months (as detected in Santa Cruz, ~17 S), while south of Mariscal Estigarribia (~22 °S) there are more jet episodes detected during the cold season. This is a first indication that mechanisms organizing low level jets at these latitudes during both warm and cold seasons may not be the same.

In principle, SALLJ events seems to occur all year long, which is different from the LLJ of the US Great Plains that is restricted to the northern summer only. The SALLJs bringing tropical moist air masses from the Amazon into southern Brazil-Northern Argentina are more frequent in the warm season, and the SALLJs bringing tropical maritime air less humid than the tropical air masses coming from the Subtropical Atlantic High are more frequent during the cold season (Fig. 5). SALLJs are detected mostly during the warm season to the North of ~20 °S, while to the south the SALLJs seem to peak in winter.

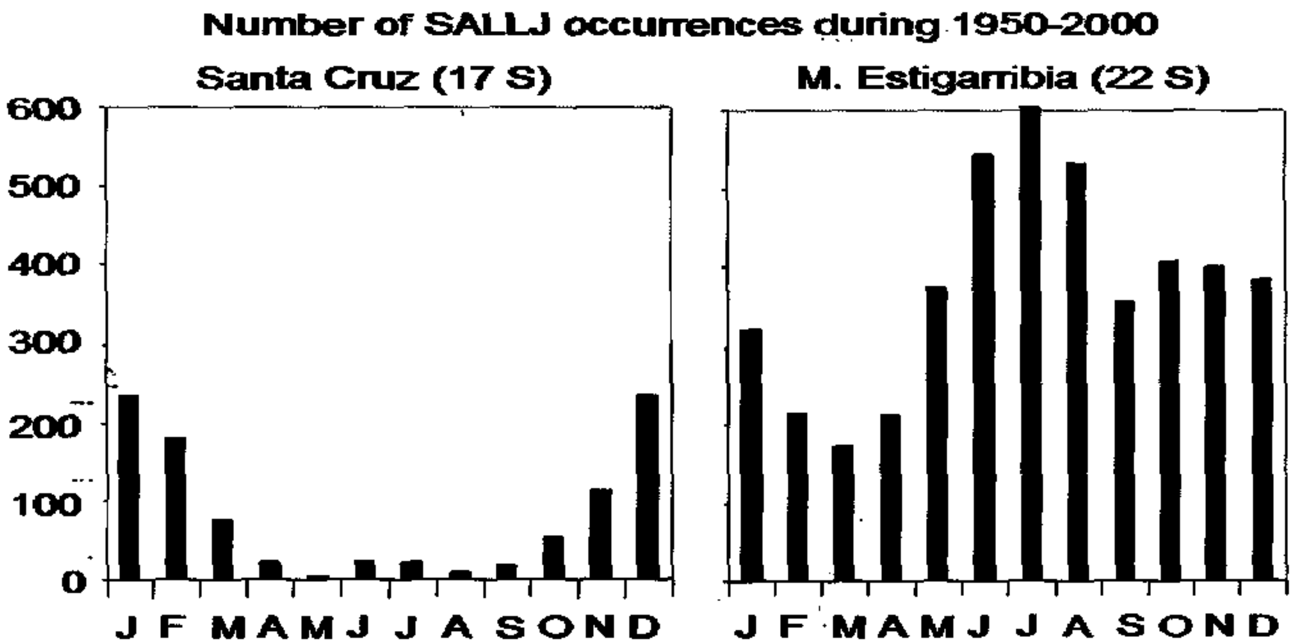

Figure 4. Annual cycle of SALLJ occurrences in Santa Cruz (17 S) and Mariscal Estigarribia (22 S) as derived from the NCEP reanalyses (Marengo et al. 2004).

Interannual variability

Time series of frequency and intensity of SALLJ episodes during 1950-2000 are shown in Fig. 6 for Santa Cruz (warm season) and Mariscal Estigarribia (cold season). There is not a clear association between the occurrence of El Niño or La Niña and the number and the intensity of SALLJ in both sites. During the period with available PACS-SONET pilot balloons in Santa Cruz, the number of SALLJ events during the strong El Niño 1998 was 29 events and La Niña event of 1999 featured only 7 events. The intensity of the winds based on the average for the time with the maximum wind speed from the reanalyses (06-12Z) shows that the strongest events were observed during 1997-98 while the episodes during the middle 1980's and early 1990's were relatively weaker. Few studies using the PACS-SONET upper air data have suggested enhanced SALLJ activity during 1998 as compared to weak activity in 1999 (Douglas et al. 1999, Marengo et al. 2002, 2004). In Fig. 3, the reanalyses suggest less episodes of SALLJ in 1999 as compared to 1998, but the lack of observations during other El Niño events does not allow for a general conclusion between the presence of El Niño and a more active SALLJ season.

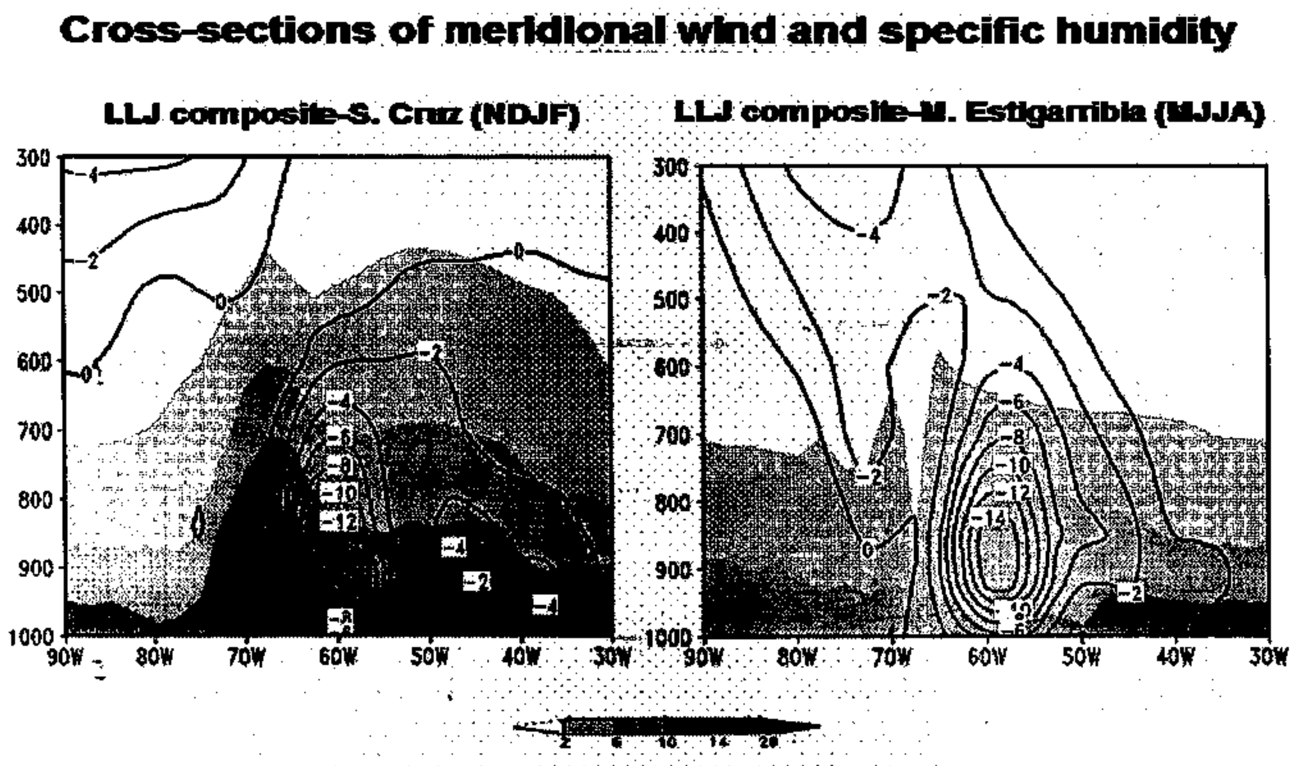

Figure 5. Meridional cross section of meridional wind component (line-m/s) and specific humidity (shades), along Santa Cruz during austral summer NDJF and Mariscal Estigarribia in winter (MJJA), for SALLJ composites.

Decadal and long term variability

In order to identify the potential role of SST of the tropical oceans, and the SALLJ activity in longer time scales, Marengo et al. (2004) shows regression maps of the number of warm season SALLJ detected in Santa Cruz and SST anomalies during spring and early summer for the 1950-2000 period. The maps show positive and statistically significant correlations between the SALLJ frequency and SST anomalies in the Pacific Ocean, while the correlations in the tropical Atlantic are very weak. However the correlations barely surpass 0.4, implying that less than 20% of the SALLJ variance can be explained by the SST anomalies in the tropical Pacific. The size of the correlations indicates a more important role of tropical Pacific SST anomalies during September. Marengo et al. (2004) suggest that warm SST anomalies in the tropical Pacific excited an anomalously east-west overturning with sinking motion and low-level easterlies in northern Brazil. These easterlies turn southwestward when encountering the Andes, enhancing the SALLJ activity and increasing rainfall was detected over southern subtropical South America, while the SACZ was weak.

Fig. 7 shows time series from 1950-2000 for the SALLJ occurrences during the warm season in San ta Cruz, together with indices that describe El Nino and El Nin-Like conditions: SOI, SST Nino 3.4 and the PDO. All the figures show the climate shift that occurred in the Pacific around the late 1970s, that suggested a turning towards El Nino like conditions after the middle 1970's (represented by systematic warming in the tropical and extratropical Pacific (NINO3.4 and PDO, consistent with negative tendency in the SOI index) and consistent with increment of SALLJ activity. This is consistent with the correlation analysis from Fig. 4, but the potential for predictability is low since the SST anomalies in the tropical Pacific explains for less than 20% of the SALLJ variance.

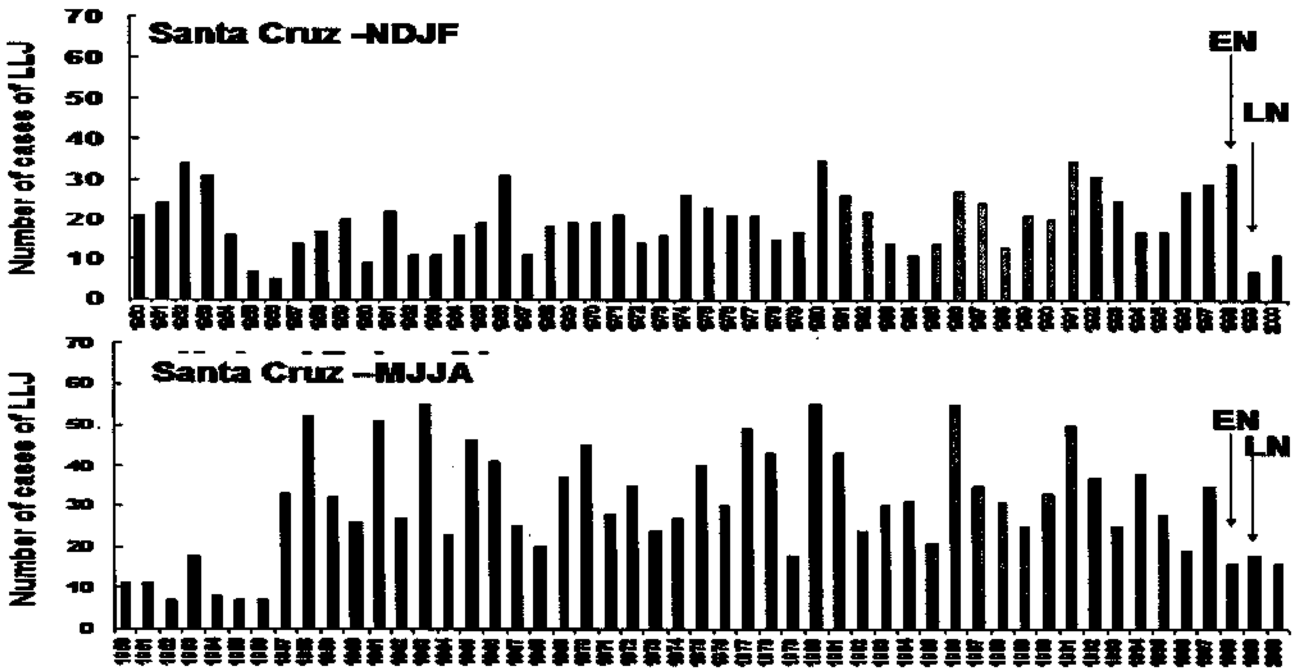

Figure 6. Interannual variability of the number of SALLJ during summer in Santa Cruz and in winter in Mariscal Estigarribia. EN indicates the \precence of El Niño year. (Marengo et al. 2004).

Future climate change scenarios

For climate change scenarios for the XXI Century, new developments in dynamic vegetation schemes and coupled climate-carbon models (Cox et al. 2000, Betts el al. 2004) have shown an effect named *die-back of the Amazon forest*, by which rising atmospheric CO2 is found to contribute to a 20% rainfall reduction and to more than 30% of surface temperature increases in the Amazon basin, through the physiological forcing of stomatal closure. They also show an increase in rainfall in southern Brazil-northern Argentina. The observed small negative rainfall trends in northern Amazonia, and systematic increases in rainfall and runoff in southern Amazonia and southeastern South America region since the middle 1970s (Marengo 2004) is consistent with the increase in the frequency of SALLJ events. Thus, it could be hypothesized that following Betts' results from the HadCM3 model that after the middle 2050s, the drying of the Amazon basin and the humidification of the southern Brazil-northern Argentina region in an extended El Nino-mode produced by this model, could be explained by changes in the regional circulation, with an increase on the SALLJ frequency and/or intensity in a global warming world. The likelihood of this scenario, however, is still an open issue.

DISCUSSIONS AND CONCLUSIONS

An overview of past observational studies has left the diurnal wind cycle (particularly the nocturnal phase) and the three-dimensional structure of the SALLJ inadequately resolved. It is of interest to determine the advancement obtained in the characterization of the low-level circulation allowed by the increased spatial and temporal resolution in wind observations during SALLJEX and identify some remaining gaps for further advancements. The current operational upper air network (twice-d-day observations) does not resolve this problem, and the analysis of the SALLJEX field experiment data are helping in depicting better de diurnal cycle of the SALLJ and its circulation and rainfall characteristics.

SALLJ episodes are detected all year long, with 75% of the cases detected during November-February at along the axis of the SALLJ near by Santa Cruz, and 25% occurring mostly during the cold season. In Mariscal Estigarribia located nearby the exit region of the SALLJ, 45% of the cases were detected during the cold season and 29% during the warm season. The source of moisture is the tropical and subtropical Atlantic, while during the summertime SALLJ the most important source are the northeast winds deflected to the southwest, with enriched moisture content provided by the Amazon Basin. At interannual time scales, even though more there have been identified frequent and stronger SALLJ episodes during El Niño 1998 as compared to La Niña 1999, there are not strong statistical evidence that suggest that more SALLJ episodes are detected during El Niño years or less strong or frequent SALLJ during La Niña years. The low percentage of the variance of SALLJ explained by tropical Pacific SST anomalies, and the warming tendencies detected since the middle 1970's is consistent the increased SALLJ activity since this period. This scenario seems to be consistent with a global warming scenario in the 2050's, where the drying of the Amazonia and the humidification of the southeastern South America on an extended HadCM3 model generated El Nino mode could be related perhaps tom more intense and/or frequent SALLJ as a consequence of global warming.

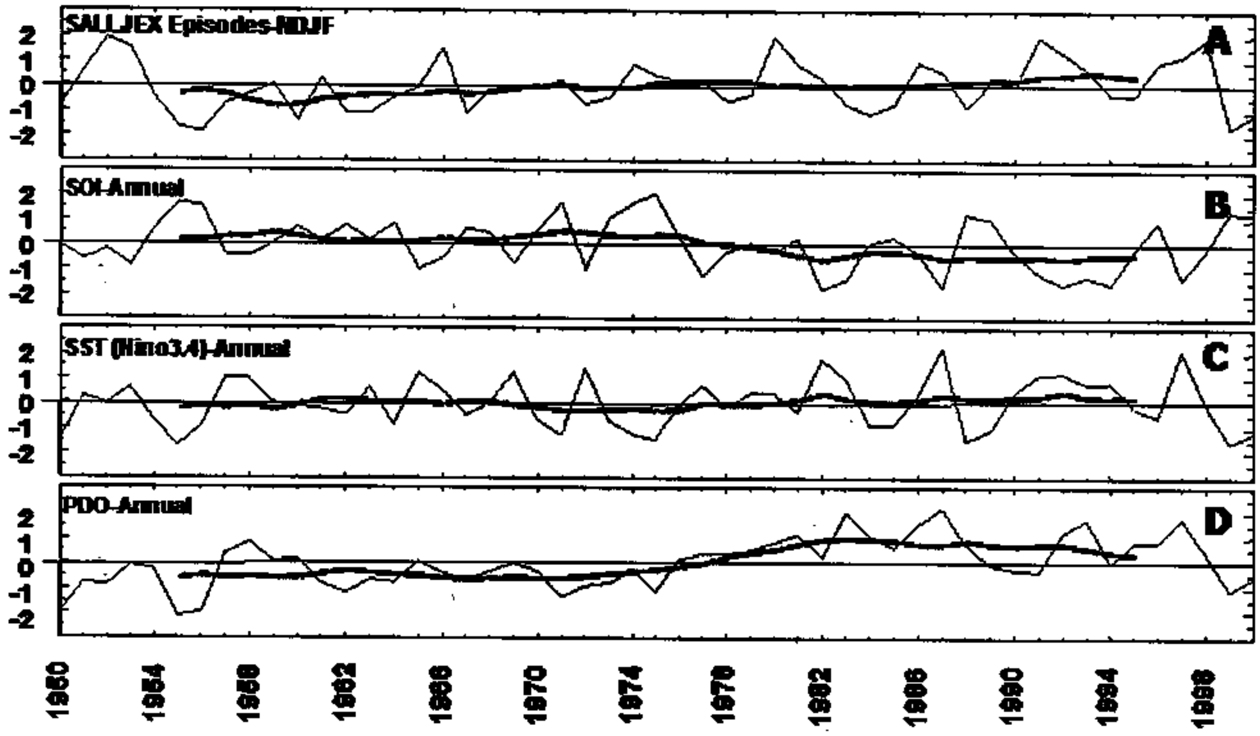

Figure 7. Normalized departures of SALLJ occurrences and indices of the Southern Oscillation (b-Annual SOI; and c-SST El Niño 3.4). The Pacific Decadal Oscillation (PDO) is shown in (d). Thick line represents the 11 year moving average.

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