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THERMODYNAMIC AND KINEMATIC CHARACTERIZATION OF THE LOW-LEVEL TROPOSPHERE DURING SALLJEX UNDER DIFFERENT LARGE-SCALE ENVIRONMENTS

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1. INTRODUCTION

In the last decade a significant effort has been devoted to improve the observational resources over South America. Field experiments like the Large-Scale Biosphere Atmosphere Experiment in Amazonia (LBA) and the South American Low-Level Jet Experiment (SALLJEX) are prominent examples of this regional challenge. Particularly, this last experiment conducted under the CLIVAR's VAMOS program during the warm season period 15 November 2002 to 15 February 2003, was performed in Bolivia, Paraguay, central and northern Argentina, western Brazil and Peru. SALLJEX aimed to monitor, quantify and analyze the low-level circulation over this region and its variability (Nicolini et al. 2004a, Vera et al 2006 and references therein). SALLJEX data set provides a quantitative improvement in both spatial and temporal resolution over the operational upper-air network (see Fig. 1 for the topographical map and upper-air network sites during SALLJEX).

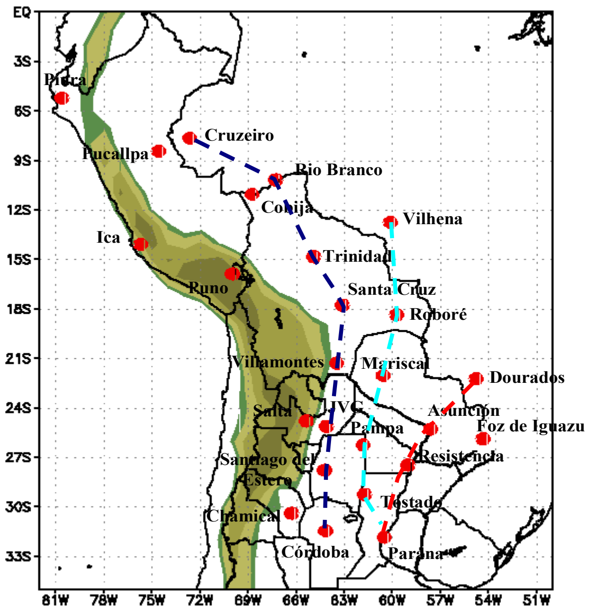

Figure 1: Geographical distribution of SALLJEX stations and topography with terrain altitudes higher than 500 m. Transects are displayed in dash lines: TWEST in blue, TCENTRAL in light blue and TEAST in red.

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Early findings related to low-level circulation depicted in SALLJEX data have been documented by Nicolini et al. 2004a. They addressed the SALLJ diurnal cycle and three dimensional structure based in a preliminary upper-air sounding data set and in the research flight missions from the NOAA WP-3D aircraft. Their results illustrate the vertical and horizontal structure of the low-level flow during a particular P-3 mission given by the series of ascents and descents and indicate a spatial variability in mean summer behavior in low-level wind diurnal cycle both in the magnitude of the maximum speed in the vertical wind profile and in the rotation of the wind vector. They also show the benefit of stratifying the data in subsamples characterized by different synoptic patterns dominated by the presence or absence of the SALLJ within the region. The first two samples Chaco Jet Events (Nicolini and Saulo, 2000, denoted as CJEs), and no-CJEs integrate the SALLJ sample dominated by the presence of a low-level jet (LLJ) bounded by the Andes, immersed in low-level poleward flow that extends from equatorial latitudes toward subtropical Argentina. The main difference between them resides in the poleward extension of the jet core. The third sample (no-SALLJ) consists in a variety of environmental conditions associated with different synoptic patterns. An interesting result is that while the jet core remains limited to tropical latitudes during SALLJ events, the no-SALLJ vertical wind profile composite reveals the presence of a LLJ that generates locally over subtropical northwestern Argentina (clearly depicted at Santiago del Estero). Further stratification of the wind data in order to isolate the synoptic patterns that foster the occurrence of this maximum was addressed by Nicolini et al., 2004b and the new LLJ category was denoted as Low-Level Jet Argentina (LLJA). This LLJ is typically immersed in a northeasterly flow in the west sector of a postfrontal anticyclone located to the east of the Andes.

Figure 2 shows a schematic of the low-level flow for each subsample CJE, no-CJE and LLJA, respectively. A motivation for this stratification of the environmental conditions is the increasing evidence that these three excluding patterns have different (and still under study) impacts in the spatial distribution, intensity and time phasing of convection/precipitation and in the moisture convergence area downwind the corresponding wind speed maximum (Nicolini et al. 2004c, Salio et al. 2004, Nicolini and Saulo 2006, Salio and Nicolini 2006).

Afterwards, a careful quality control of SALLJEX sounding and surface data has been performed to build up a reliable data set. Progress in this direction allows a further thermodynamic and kinematic structure characterization of the low-level troposphere during SALLJEX. Besides, this characterization during one warm season provides elements to identify the preconditioning and/or triggering processes for severe weather including boundary layer processes related to LLJs. This controlled data set is also currently used for implementing downscaling and data assimilation in operative analysis for impact studies in short range forecasts and, as mentioned before, for research in mechanisms controlling SALLJ and its related precipitation (see Borque et al. 2006 and Garcia Skabar and Nicolini 2006, this same Conference).

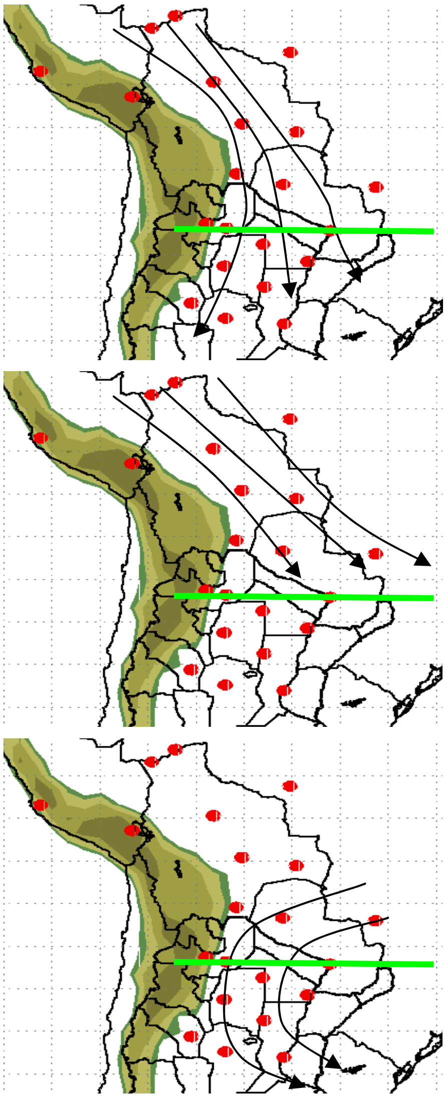

Figure 2: Scheme of the circulation of the wind in low levels under three characteristic low-level jet events over Southeast South America. Chaco Jet Event is outlined at the top, on the center No Chaco Jet Event and at the bottom the Low-Level Jet Argentina scheme. The area shaded in light blue display the isotach of $12 ms^{-1}$. The green line indicates the latitude of 25°S.

A first study using operational fields from NCEP (Global Data Assimilation System - GDAS) and the aforementioned SALLJEX upper-air controlled data set (both thermodynamic and kinematic variables) was done by Nicolini et al. (2005). This study focused in analyzing nocturnal and daytime vertical profiles of thermodynamic variables at Resistencia and Santiago del Estero (Argentina) and the vertical structure of the wind at 12 UTC over the Bolivia, Paraguay and Argentina domain of the SALLJEX observational network, under the two strong LLJ events CJE and LLJA. The first characterization of the stratification in Santiago del Estero documented by Nicolini et al. (2005) reveals a deep convectively unstable layer during the afternoon up to 4000 m in the CJEs composite with surface equivalent potential temperatures cooler respect to Resistencia where higher specific humidity values dominate. Mixing layer is deeper during CJEs respect to LLJA in both stations. Despite the progress done in the aforementioned characterization, the limitation of the wind analysis to only 12 UTC does not allow a diurnal cycle description and its variability characterization over the region. Also, it is important to extend the thermodynamic analysis to other stations within SALLJEX network besides Resistencia and Santiago del Estero.

The purpose of this work is to characterize the spatial variability of the main low-level vertical thermodynamic and poleward wind profile features as well as their diurnal cycle under different environmental conditions over the SALLJEX region.

2. DATA AND METHODOLOGY

Upper-air sounding SALLJEX data set used for this study covered the 3-month observation SALLJEX period and included radiosonde (RAOBS) and pibal observations. In order to allow the simultaneous analysis of both sounding data all the observations have been interpolated every 100 m to the same elevations over the sea level from the station altitude.

For the identification of the three LLJ categories the same criteria used in Nicolini et al., 2004b have been implemented in GDAS analysis and complemented with SALLJEX data. The number of days that compose the 3 categories are: 45 CJE days, 16 no-CJE days and 14 LLJA days.

As composite technique a simple average of thermodynamic and wind variables was computed for the whole SALLJEX period and for each category, respectively. Composites at SALLJEX stations are mostly confident during 06 UTC to 12 UTC and 18 to 21 UTC and very few wind observations have been done every 3 hours at any other time (only during IOPs). Observations at 6 UTC are only confident at sounding stations (Santa Cruz de la Sierra, Santiago del Estero, Resistencia and Mariscal Estigarribia). Hours more representative of nocturnal and daytime period are 06 (03 am local time) and 18 UTC respectively whereas 12 and 00 UTC being transition times, have however a more nocturnal and daytime regime, respectively. GDAS composites of atmospheric synoptic fields have already been analyzed (Nicolini et al., 2005) and the main synoptic patterns that dominate each LLJ category have been identified.

3. RESULTS

3.1 Discussion of performance of the selected LLJ identification criteria

It is of interest to verify how representative the conditions used in the Bonner criterion 1 (Bonner, 1968) adjusted version for the SALLJEX domain, are to determine in a regional scale if a particular day qualifies as a CJE, no-CJE or else as a LLJA. In this adjusted Bonner criterion 1 version, the LLJ identification criteria based on GDAS wind field analysis at synoptic times 06, 12 and 18 UTC, was modified using SALLJEX data. The effect of this data input was to increase the number of CJEs, to reduce LLJA days, mainly as a result of redistributing a substantial number of no-LLJ (according to GDAS) in other categories.

Santa Cruz and Mariscal Estigarribia are the SALLJEX stations that always entered the SALLJ identification criteria and will be used as primary test stations to determine how frequently happens that a day with a jet like profile has not been included in one of the LLJ categories already defined. As shown in Fig. 3a, jet like profiles at Santa Cruz with maximum wind speeds slower than 12 ms^{-1} mostly correspond to LLJA cases, yet, some SALLJ events are also included. The majority of CJEs exceed the 12 ms^{-1} threshold and almost no real jet profile was classified as no-LLJ at Santa Cruz, taking into account the whole layer between 500 and 2500 m asl within which the observed maximum occurs. At Mariscal Estigarribia, the Bonner speed threshold mainly separates CJEs from the other LLJ cases with some classified as no-LLJs that exceed this threshold (Fig. 3b). Southward in the SALLJEX region a similar analysis at stations near the mountains like Santiago del Estero and Joaquin V. Gonzalez (not shown) shows a larger number of cases classified as no-LLJ in the weaker than 12 ms^{-1} subdomain (Fig. 3c), indicating a bias in the classification criteria toward moderate and strong LLJs (both SALLJ and LLJA). This exclusion of weak LLJ cases from the LLJ subsamples is less apparent at other Argentina stations like Resistencia (Fig. 3d) and Pampa de los Guanacos (not shown). An analysis of the LLJ shear above the maximum speed arrives to values comparable or stronger to the ones defined by Bonner at least at the times when the LLJ is well defined.

In synthesis and for the 3-month period, it appears that the selected criteria is capable to identify the presence of SALLJ or LLJA events not only in a regional scale but also at individual locations with a preference for moderate to strong events at the Argentina stations more near the Andes. Studies focused in vertical wind profile structure at particular stations for different low-level atmosphere applications require further analysis on a local base taking into account diurnal variability and the data limitation in time resolution.

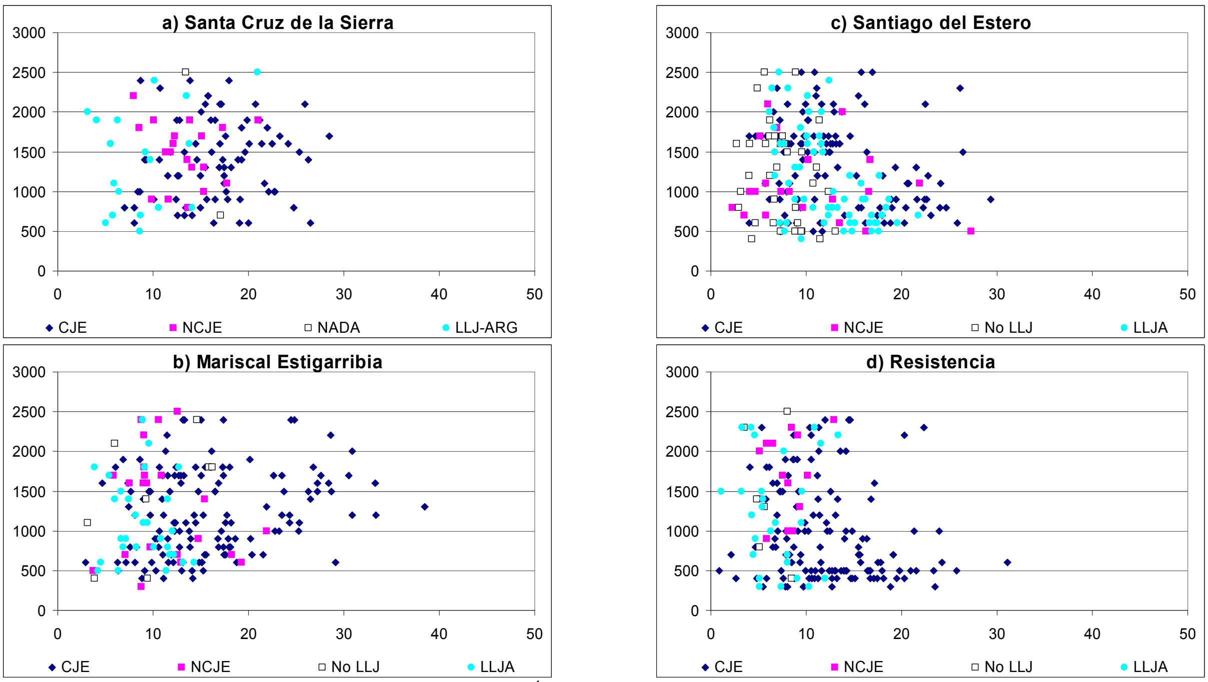

Figure 3: a) Intensity of a northerly wind maximum (m s^{-1}) with a jet like structure versus altitude (m) for each synoptic situation at Santa Cruz de la Sierra, b) Mariscal Estigarribia, c) Santiago del Estero and d) Resistencia.

3.2 Analysis of the whole SALLJEX wind data set

The first approach to study the variability of the wind profiles is to analyze the whole SALLJEX data set. With this purpose, three different transects have been defined to better explore the spatial variability and to emphasize differences among sounding stations located along them. They are meridionally oriented, one starting at Cruzeiro and running nearer the Andes from Santa Cruz de la

Sierra (Fig. 1, denoted as TWEST), the second centered in a more central longitude starting at Vilhena (denoted as TCENTRAL), the third positioned more to the east, extending from Dourados to Paraná (denoted as TEAST). The times selected to composite the wind speed profiles are limited to 09, 12, 18 and 21 UTC given the few observations available at any other time.

Composites of SALLJEX wind profiles along TWEST (Fig. 4) illustrate some interesting features. A signal that stands out is the opposite behavior in the phase of the maximum speed at Santa Cruz respect to the other stations in this same transect. This phase occurs in the afternoon and persists in the evening whereas in the other stations clearly occurs not later than sunrise. However, mean wind speed maximum for jet like profiles verifies at 12 UTC (18 m/s) and not in the afternoon as SALLJEX mean profiles seem to indicate. This finding suggests that the inclusion of different synoptic situations in the SALLJEX sample hides the diurnal cycle for LLJ cases. A decrease in the maximum is apparent from Cruzeiro to Rio Branco, followed by an increase up to Trinidad once the current has been mechanically forced to deviate southeastward, to decrease again poleward of this location. A search in the four transects for a shift in time in the phase of the maximum at lower latitudes is not clear in the whole SALLJEX sample.

Nicolini et al. (2004b) have already obtained maps of observed winds for different hours of the day. They found an anticlockwise gyre during nocturnal time consistent with an inertial oscillation stronger at subtropical latitudes and an opposite rotation during daytime with an easterly component at nightfall toward low pressure at a time of deepening of the Northwestern Argentina thermal Low (NAL) and coincident with the plain component of a mountain-plain circulation between the Andes, the Paraná River valley, and the southern Brazil mountain range (Nicolini et al, 1987; Nicolini and Saulo, 2006). However, the occurrence of southerly winds after summer cold air incursions and migratory anticyclones passages, especially over the Argentinean sector, provide synoptic variability to this whole period analysis. Questions like what particular environmental conditions favor the afternoon maximum in the wind speed profile at Santa Cruz (or at other locations just east of the mountains) or a possible delay in the phase of this maximum with a decrease in latitude may be explored after stratification of the data is done and the composites for the defined categories are analyzed.

TWEST

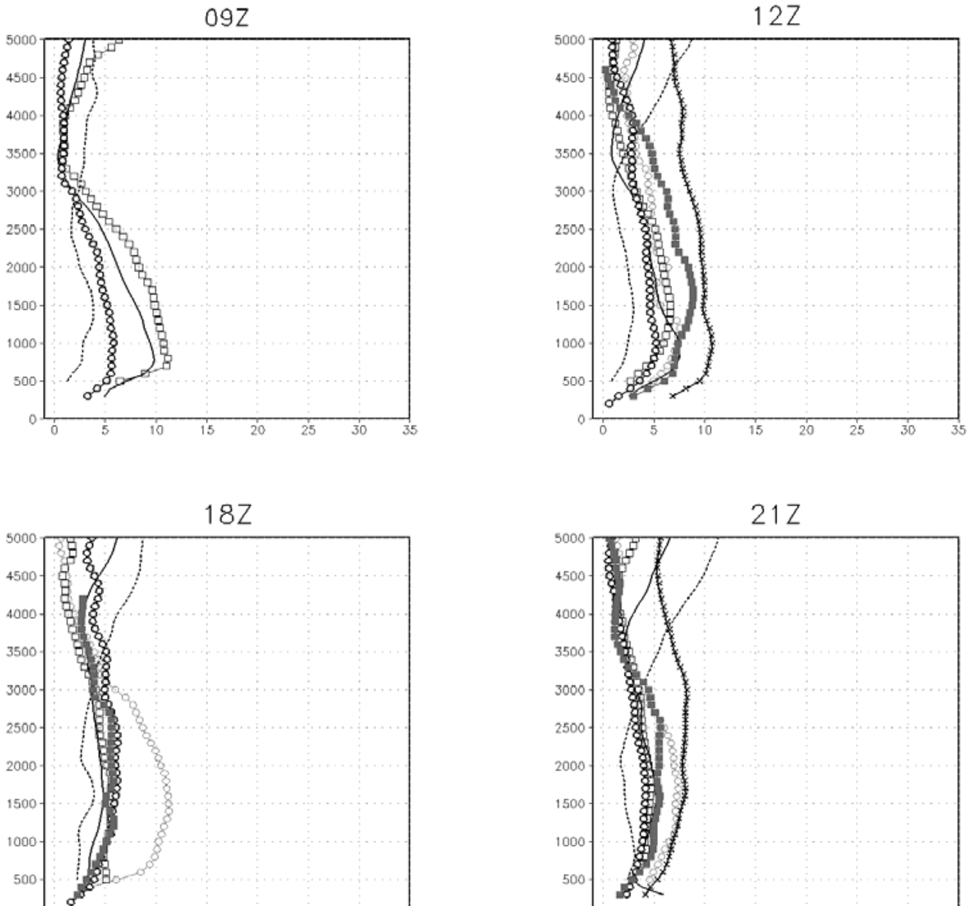

Figure 4: Composites of SALLJEX wind profiles along TWEST transect (Cruzeiro: grey closed square; Río Branco: black open circle; Trinidad: black cross; Santa Cruz de la Sierra: grey open circle; Joaquín V Gonzalez: open square; Santiago del Estero: solid line; Córdoba: short dash).

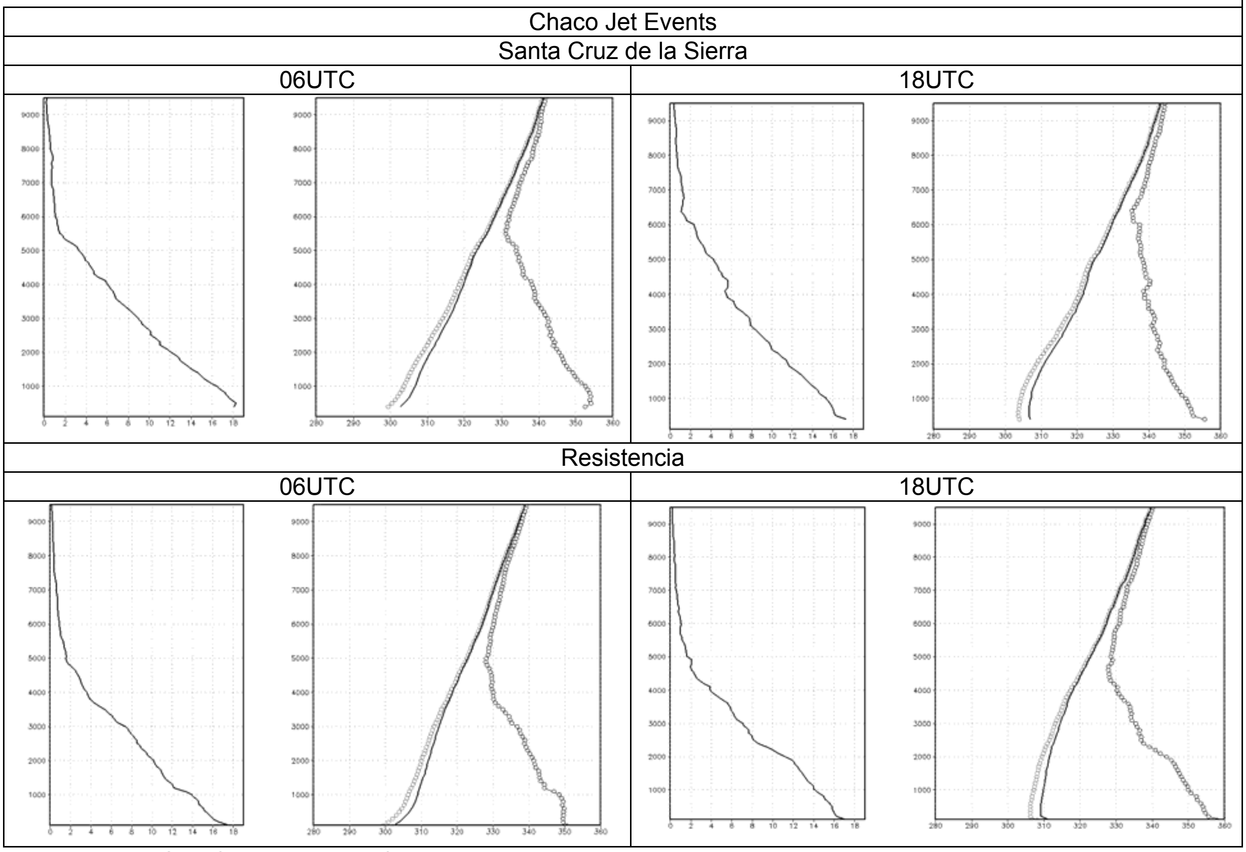

Figure 5: Specific humidity on left panel (solid line) and equivalent potential temperature (open circle, black line), potential temperature (solid line) and virtual potential temperature (open circle, grey line) on right panel for the composition of Chaco Jet Events at 06 and 18 UTC at Santa Cruz de la Sierra and Resistencia.

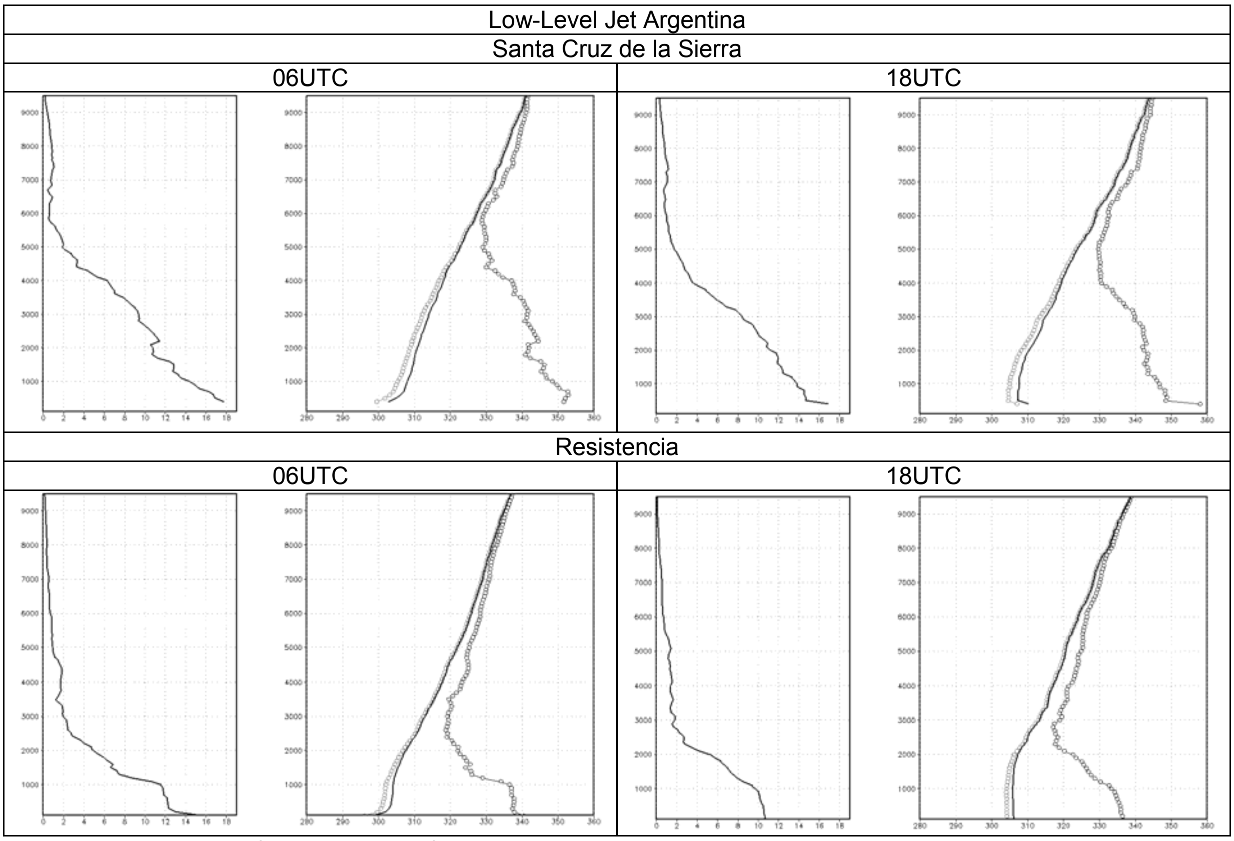

Figure 6: idem Fig 5 for compositions of Low-Level Jet Argentina Events.

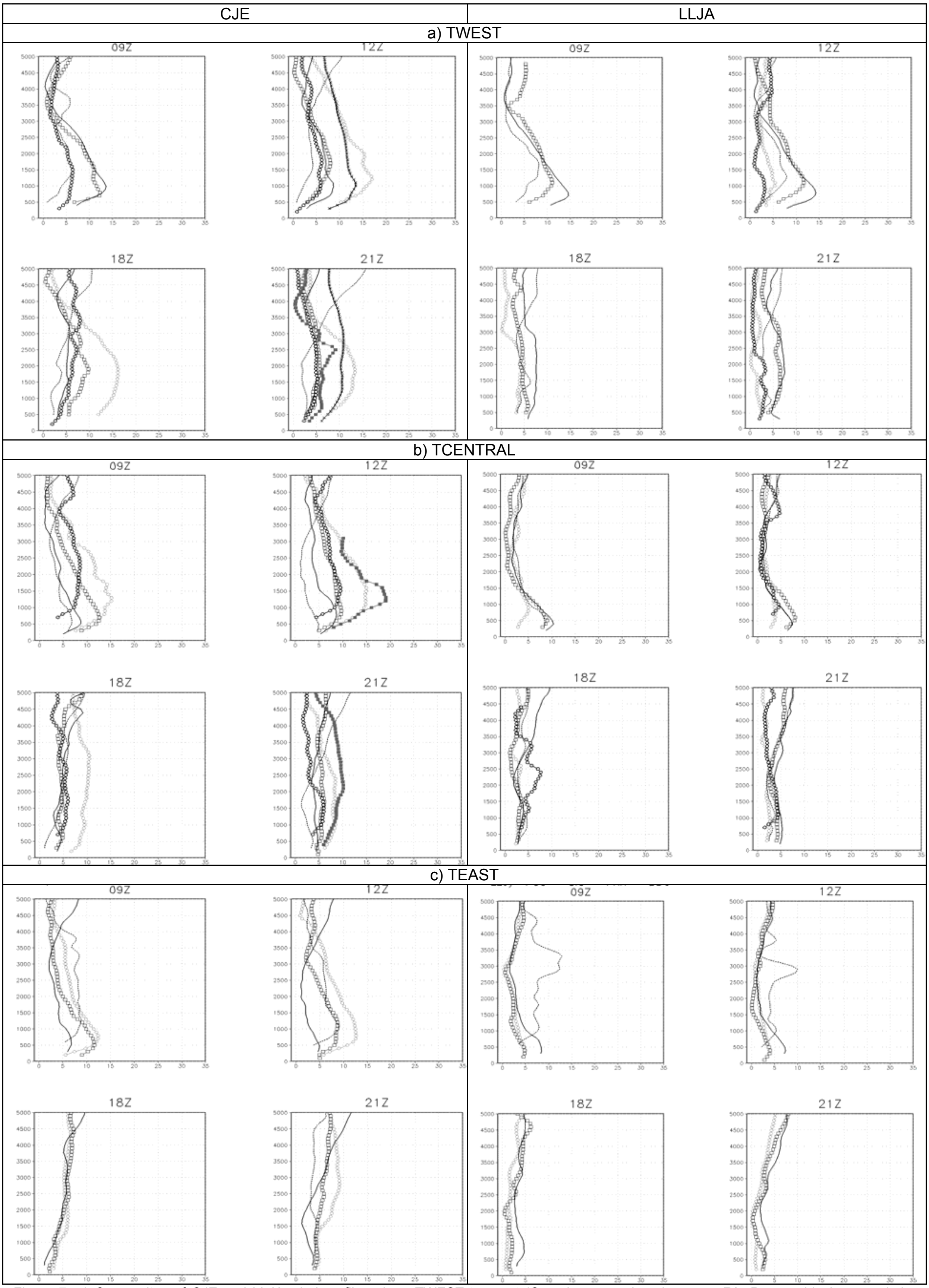

Figure 7: a) Composites of CJE and LLJA wind profiles along TWEST transect (Cruzeiro: grey closed square; Río Branco: black open circle; Trinidad: black cross; Santa Cruz de la Sierra: grey open circle; Joaquín V Gonzalez: open square; Santiago del Estero: solid line; Córdoba: short dash). b) idem as a) along TCENTRAL transect (Dourados: short dash; Asunción: grey open circle; Resistencia: open square; Paraná: solid line). c) idem as a) along TEAST transect (Vilhena: black open circle; Roboré: grey closed square; Mariscal Estigarribia: grey open circle; Pampa de los Guanacos: open square; Tostado: solid line; Paraná: short dash).

3.3 Discussion of main features in thermodynamic and wind vertical profiles under different categories of LLJs.

Greatest differences in the thermodynamic structure are found between CJE and LLJA events (equivalent potential temperature θe and specific humidity qv) at low-levels (see Fig. 5 and 6 respectively).

Low levels are wetter and convective instability conditions are more clearly defined during CJEs through a deeper layer respect to NCJEs over Argentina. It is interesting to note that the PBL at Resistencia is as moist as at Santa Cruz under CJEs conditions but the diurnal heating (apparent in the potential temperature θ diurnal changes and the convective instability) is stronger at the former station. Also, strong winds at Mariscal Estigarribia favor more vertically homogeneous profiles of θe, θ and qv (especially in the afternoon) in clear skies during CJEs.

The mixed afternoon mixing layer is more clearly defined during LLJA environments (largely due to clear skies and anticyclonic conditions). The subsidence effect at Resistencia drastically reduces the mixing layer depth to around 1000 m. This is in clear contrast to the CJEs vertical structure.

During CJEs, vertical wind profiles along TWEST transect (fig. 7) display an extreme maximum at Santa Cruz and a progressive weakening in wind speed downstream toward Santiago del Estero and Córdoba. This jet like profile is more prominent at 12 UTC, and persists in the afternoon not only at Santa Cruz but at all the Bolivian stations as well as at J.V: Gonzalez (the SALLJEX station closest to the slope of the Andes). The altitude of this LLJ rises in the afternoon hours at the same time that reduces its intensity.

It is interesting to note the shift in time of the phase of the maximum speed between tropical and subtropical stations. Mariscal Estigarribia and Vilhena (TCENTRAL) present a maximum at 12 UTC while at Pampa de los Guanacos it appears at 9 UTC. This behavior is also evident between Paraná and Asunción (TEAST).

During LLJA conditions the analysis of the wind profiles may be restricted to subtropical stations due to the dominance of southerlies at Santa Cruz (not shown). Easterlies are prevalent in eastern Argentina while the anticyclonic circulation induces northerlies close to the mountains. Coherent with this circulation TWEST shows a LLJ maximum at Santiago del Estero between 9 to 12 UTC. This jet is also evident at J.V. Gonzalez, Córdoba and Paraná (TWEST and TEAST) where it presents a longer duration than during CJEs. The LLJA diurnal cycle is well defined, the phase of the minimum is evident in the absence of an afternoon jet profile over the whole subtropical region.

Anticlockwise turning of the wind vector at the level of the maximum wind in the hodograph composites is more clearly defined during CJEs over Paraguay and northern Argentina (not shown).

Regarding NCJEs the analysis is not included due to the limited number of observations in the tropical subdomain, where the LLJ dominates, that gives less confidence to the results.

Present analysis provides a characterization of the main features of the LLJ structure and diurnal cycle and its spatial variability. This characterization is a first step in the progress to study the mechanisms that generate and control the life cycle of the SALLJ. Current research in this direction is in progress focusing on case studies during SALLJEX, like the one that motivated the papers by Borque et al. (2006) and Ruiz et al. (2005).

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