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TRANSPORT OF BIOMASS BURNING PRODUCTS IN SOUTHEASTERN SOUTH AMERICA AND ITS RELATIONSHIP WITH THE SOUTH AMERICAN LOW LEVEL JET EAST OF THE ANDES

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1. INTRODUCTION

The low-level jet east of the Andes (South American low-level jet (SALLJ)) is a wind maximum immersed in a pole-ward warm and moist current with a cross-stream mean dimension in the mesoscale. It is a relevant feature of the South American low-level circulation and climate.

The channeling of the low-level flow results from the interaction of the easterly trade winds, the Andes barrier, the South Atlantic Subtropical anticyclone and the northwestern Argentinean low. The SALLJ is episodically interrupted by cold fronts arriving in subtropical South America.

James and Anderson (1984) found that the northwesterly flow over southern Brazil persists throughout the year. During winter the flow of tropical air into mid-latitudes has a stronger eastward component and the air flows out of South America over the Atlantic. During summer, the flow has a stronger net pole-ward component up in the mid-latitudes. Nogues-Paegle et al (1998) demonstrated that the dynamical influence of the Andes favors poleward flows east of the Andes at all times of the year.

According to Zhou and Lau (1998) a continental monsoon system starts developing during spring over South America. It is characterized by a southward shift in convection, dominant over the highland region of Central Andes and Amazonia and merging with the SACZ, while the Intertropical Convergence Zone in the eastern Pacific and western Atlantic weakens.

The SALLJ has been identified as one of the mechanisms that transport heat and water vapor from tropical to subtropical latitudes, contributing to the hydrological balance of the southeastern South American basins. It drives an important tropical-extratropical mass exchange.

Saulo et al (2000) studied the modeled northerly current during the 1997-1998 warm season and progressed on its characterization, including diurnal fluctuations and horizontal and vertical structure. They found a net convergence of moisture flux over an area that includes the Del Plata basin. The moisture convergence at the leading edge of the east of the Andes low-level jet is one of the larger scale mechanisms that force relatively smaller scale convection and feed and control the life cycle of the mesoscale convective systems (Nicolini et al, 2002).

Paegle (1998) pointed out the importance of the low level jet as an agent to transport and mix other biogeochemical substances and its possible impact on any regional climate change that could occur in association with burning and destruction of the tropical rain forest.

Previous studies have defined the Chaco jet events as extreme cases of low-level jets east of the Andes that penetrate southernmost to 25º S (Nicolini and Saulo, 2000, Salio et al, 2002). This subensemble of low-level jet events has as outstanding features a baroclinic environment, with a maximum contrast of air masses in a latitude close to 39º S, a trough centered on 65º W and a maximum of heat and moisture over northern Argentina and Paraguay. Nicolini and Saulo (2000) found that the Chaco jet events seem to integrate the warm stage of a synoptic-scale interaction between midlatitudes and the tropics. Salio et al (2002) found that during these events the flux of moisture and convergence at low and mid levels is significantly stronger than the summer mean. Although they represent a small fraction of the austral summer days they account for an important fraction of the precipitation over northeastern Argentina, influencing the water balance of the region.

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The aim of the present contribution is to perform an analysis and preliminary characterization of the transport of biomass burning products in South America, focusing the role played by the low-level jet east of the Andes in the transport and the impact on sub-regions of southeastern South America.

2. DATA AND METHODOLOGY

On the basis of a one-year period, the simultaneous occurrence of low-level jet east of the Andes and biomass burning was determined.

The exploratory study of occurrence of low-level jet was carried out using the analyses provided by the Global Data Assimilation System (GDAS) of the National Centers for Environmental Prediction (NCEP). This data set has one-degree horizontal resolution and is available every synoptic time (0000, 0600, 1200 and 1800 UTC), at 26 vertical pressure levels.

The occurrence of the low-level jet events was diagnosed applying modified Bonner's (1968) first criterion to model outputs, based on the strength and vertical shear of the wind field (Saulo et al 2000) and the Nicolini and Saulo (2000) and Salio et al (2002) adjusted criterion to define the sub-ensemble of SALLJ defined as Chaco jet (CJ).

The criteria were applied each day at every synoptic time for the whole year. The application of the exploratory criteria to detect the SALLJ (CJ and non-CJ (NCJ)) allowed finding another two categories of low-level jets. One of them is related to the western flank of the South Atlantic Anticyclone (the Brazilian LLJ, (BLLJ)) and the other occurs over central Argentina (the Argentinean Low Level jet, (ALLJ)).

The CAT-BRAMS modeling system (Freitas et al, 2005 and this issue) was used to simulate selected situations and to perform a more detailed analysis. The system considers the emission, transport and transformations of particulate matter (PM2.5) and CO with an on-line approach with 30 km resolution over South America.

3. RESULTS AND DISCUSSION

In agreement with previous climatological characterizations of the low-level jet east of the Andes, for the selected year (2002), this mesoscale circulation had distinct features that allowed classifying it in the various subsets previously mentioned in Section 2. These groups typically take place within different synoptic conditions, covering distinct regions and some of them contribute to the development of convective systems.

Figure 1 shows the percent relative frequencies and types of low-level jet east of the Andes obtained using the above mentioned criteria for each month.

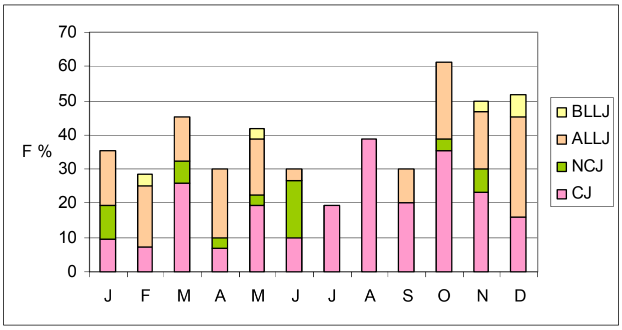


Figure 1: Monthly relative frequencies and types of LLJ during 2002.

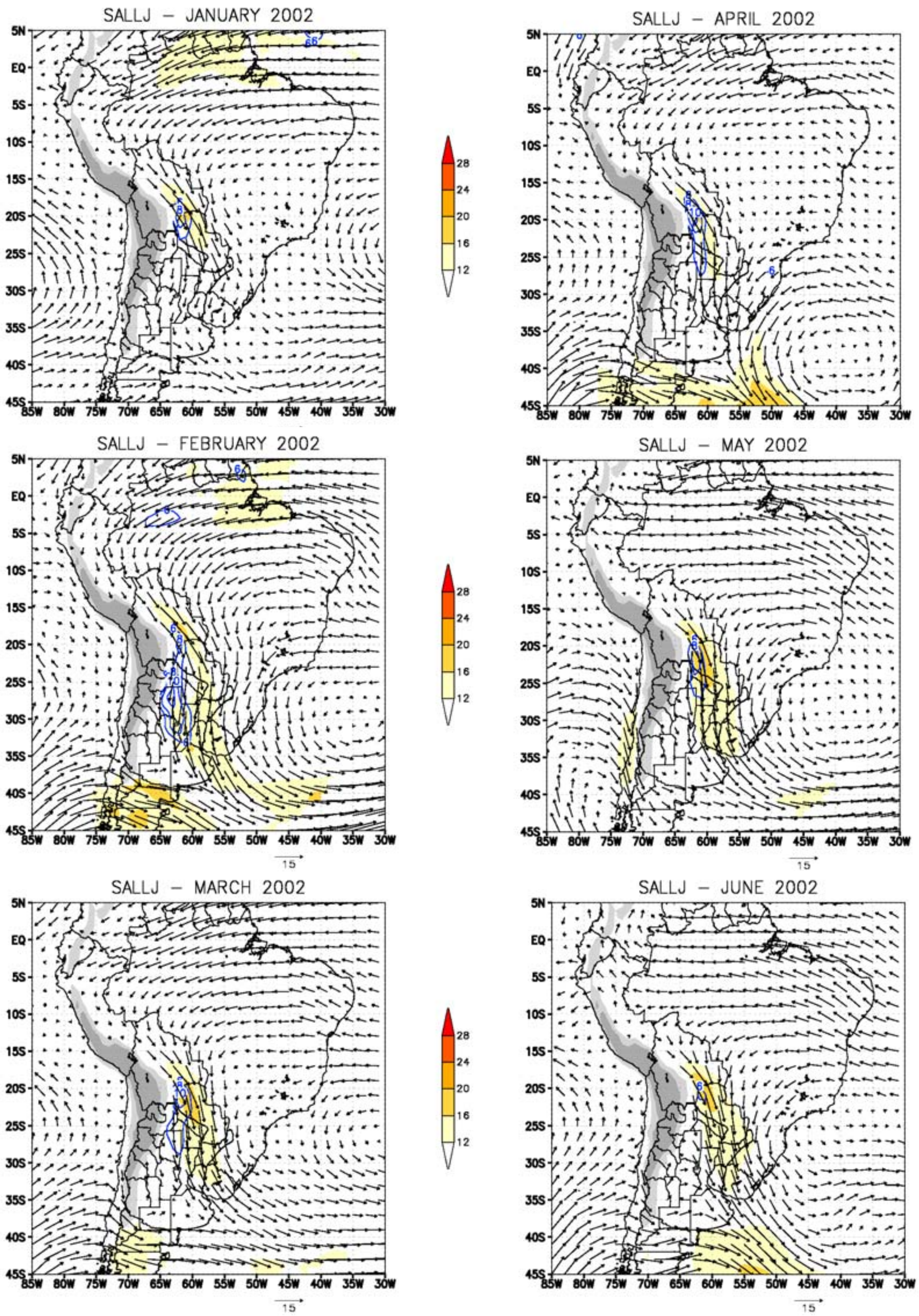
During the considered year, CJ events are relatively more frequent than NCJ events, with the exception of June. The higher frequencies of occurrence of SALLJ are observed, in decreasing order, in August, October and March. The events are present during all months.

In order to depict some of the main characteristics of the mean low-level flow, the monthly mean wind fields at 850 hPa were calculated. The northerly current east of the Andes is present during almost the whole period. There is variability in the strength and location throughout the year. Some of these features are due to the seasonal displacement of the semi-permanent systems.

January exhibits the smaller intensities over almost all South America. On the other hand, the maximum strength exceeds 12 ms^{-1} in October. The northwesterly pattern organizes at about 15º S and extends south of 25º S from March to December. The mean fields exhibit variability in the position of the exit region to the Atlantic Ocean. March, May, August, October and November are characterized by a more northerly-oriented flow. In consequence, northeastern Argentina is under its influence. During the remaining months the northwesterly orientation shows the exit region over Southern Brazil. This analysis also shows other zones with northerly flow. One of them is associated with the trade winds to the north of South America, especially during the warm period. The other region is related to the western flank of the South Atlantic anticyclone.

As the aim of the present study was to relate the low-level jet east of the Andes with the transport and dispersion of biomass burning products over the region of Brazil, Bolivia and Paraguay, we will restrict the further analysis to the SALLJ events (CJ and NCJ).

Composite fields were obtained as averages over the days that comprise each SALLJ event for each month. Figure 3 displays the wind composite fields for the identified SALLJ events.



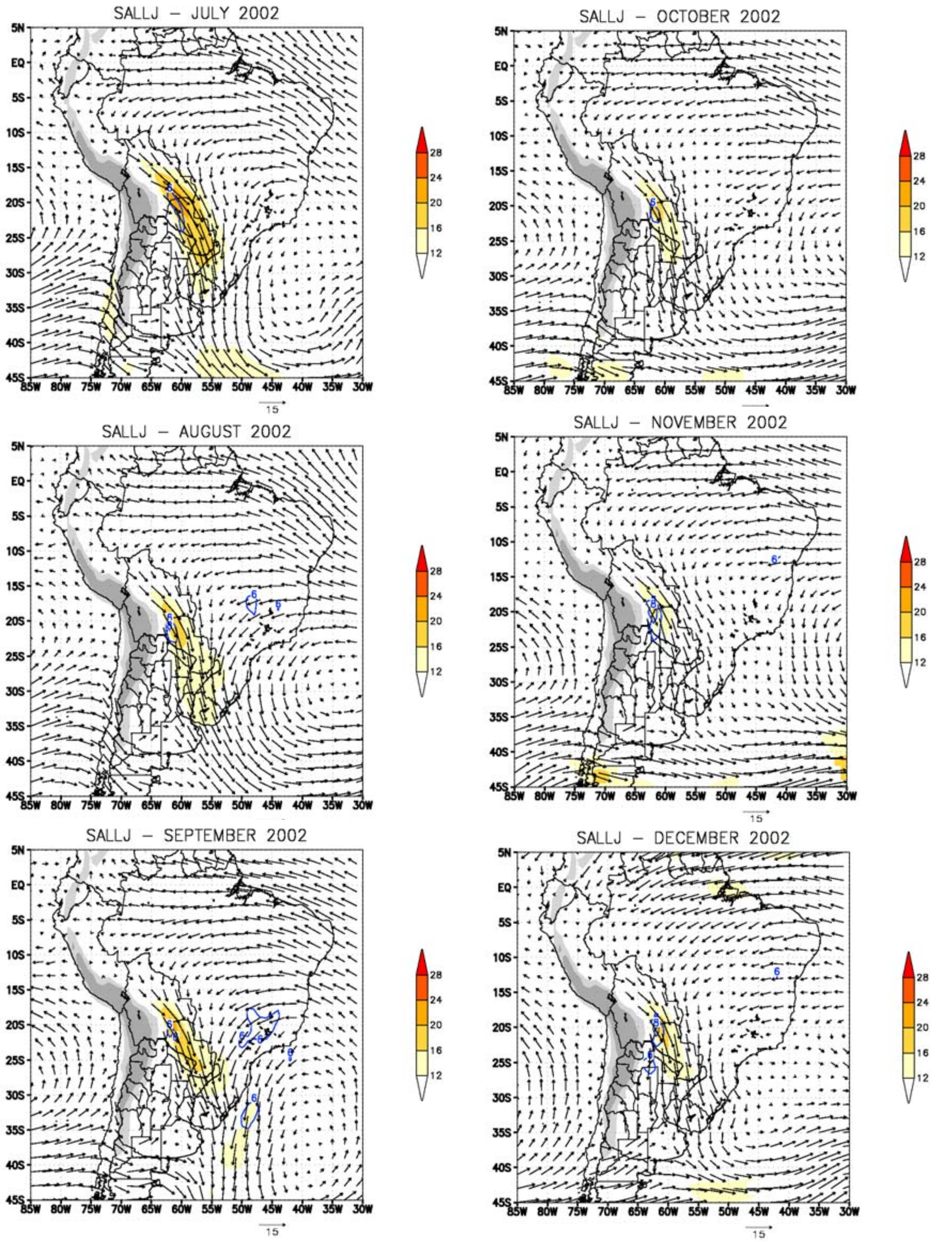


Figure 2: Monthly wind (vector); wind speed (shaded) at 850 hPa and wind shear between 850 and 700 hPa (contours) composite fields for SALLJ. Shaded corresponds to wind intensity stronger than 12 ms^{-1}. Contours denote areas with wind shear greater than 6 ms^{-1}.

In general the obtained patterns show a strong southward flow that penetrates northern Argentina and southern Brazil. These results are not unexpected because they were selected applying the established criterion. The remarkable feature is the prevalence of the CJ event pattern, which was previously outlined in the analysis of the frequencies of occurrence of SALLJ events.

The associated circulation patterns in conjunction with the occurrence of biomass burning will result in the transport of aerosols and gases towards different regions with diverse impacts.

The resulting spatial and temporal distributions of aerosols and gases obtained with the CAT-BRAMS modeling system for a particular situation are presented and studied. A prolonged CJ event that occurred in conjunction with biomass burning and took place from 23 to 28 August was analyzed. The low-level jet had an important latitudinal extent and strength with a pattern that varied according to the synoptic environment.

On 23 August the western branch of the South Atlantic anticyclone was over an important region of South America and the low level flow was from the N. A baroclinic region south of 40º S and deep low-pressure systems were moving eastward. During the following day a geopotential trough was present over central Argentina. The thickness field showed an associated maximum depth. There was a persistent N-NW flow over southeastern South America.

On 25 August there was a further deepening of the trough over central Argentina. The baroclinic region related to the cold front was located between 30º and 40º S and was moving towards the northeast. There was a strong channeling of the low-level flow between the low-pressure system and the western region of the South Atlantic anticyclone. Twenty-four hours later, the baroclinic region approached the southern region of Buenos Aires. A deep thickness trough was present over the eastern Pacific Ocean.

On 27 August the situation was almost similar, with the new system strengthening and moving eastward. The northern low-level flow was still present over southeastern South America. Finally, on 28 August the system was able to reach eastern Argentina. The associated cold front presented a nearly north-south orientation and moved eastward towards the Atlantic Ocean. The low-pressure system over Argentina deepened and the low-level northwestern flow persisted.

Figure 3a depicts the 1000 hPa geopotential height and the 500/1000 hPa thickness fields for selected days and hours (1200 UTC 25 August and 1800 UTC 28 August) during the event. Figure 3b presents the corresponding satellite images, which show the cloudiness associated with the cold front system and almost clear skies in the region of interest.

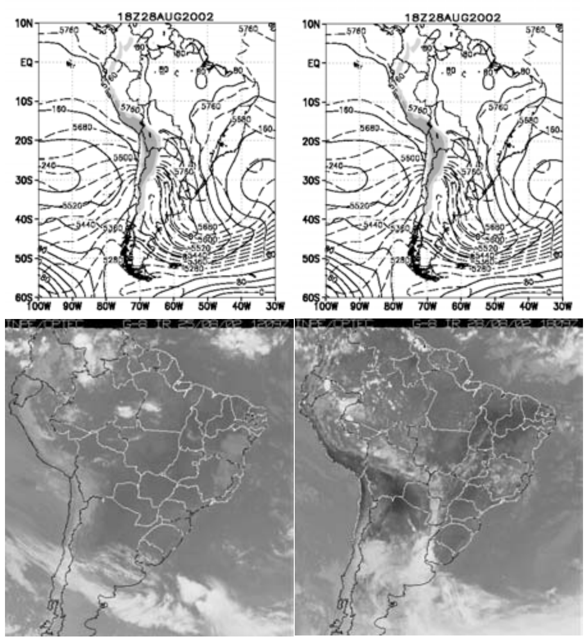


Figure 3: a) Geopotential height at 1000 hPa (solid lines) and 500/1000 hPa thickness (dashed lines) (both every 40 mgp), at 1200 UTC 25 August and 1800 UTC 28 August. b) GOES-8 satellite pictures.

Figure 4 shows the wind field at 850 hPa and the regions that verify the modified Bonner criteria for some selected hours. At 1200 UTC on 25 August the airflow shows clearly that the case belongs to the sub-ensemble CJ. The low-level flow is from the northwest. The channeling of the current is strengthened by the westward displacement of the Atlantic anticyclone. The field three days later illustrates the persistence of the pattern. The region that verifies the LLJ criteria continues to be widespread. At 1800 UTC on 28 August (not shown), a region with wind intensities greater than 12 ms^{-1} persists, but the vertical shear is less than 6 ms^{-1}.

During this particular event, an important southward penetration of the low-level jet occurred and the associated moisture convergence at the exit region of the current favored the development of convective systems south of 40º S, which strengthened mostly over the Atlantic Ocean. The interaction with the cold front further contributed to the convection.

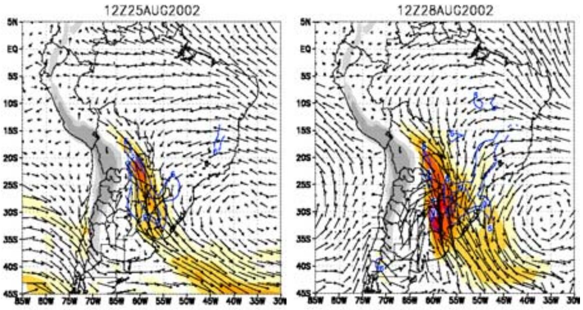


Figure 4: Wind (vector); wind speed (shaded) at 850 hPa and wind shear between 850 and 700 hPa (contours) fields at 1200 UTC 25 and 28 August. Shaded and contours are as in Fig 3.

Figure 6 shows the CO mixing ratio (ppb) and the horizontal flow at 1100 m above the surface at selected hours during the period. At 1200 UTC on 25 August the concentrations reached values as higher as 600 ppb, at 10ºS and 62º W and 500 ppb at 12º S and 65º W. A secondary maximum is observed at 25º S and 62.5º W with CO mixing ratios reaching 250 ppb. The wind flow pattern is due to the anticyclonic circulation centered on the Atlantic Ocean and the clockwise circulation eastward of the trough over central Argentina. At 1800 UTC on 28 August, the highest concentration value is 450 ppb very near the sources, over central Brazil. There is also an extended region over Paraguay, with CO concentrations of 250 ppb. Buenos Aires had a value of 100 ppb.

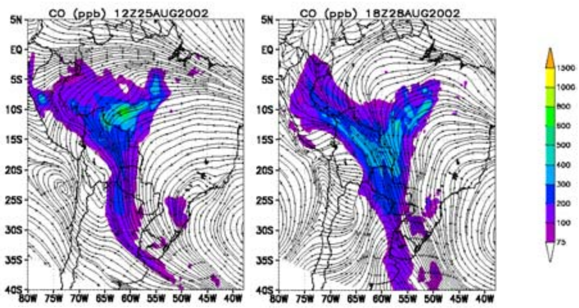


Figure 5: *Plume of CO (ppb) at 1200 UTC on 25 August and 1800 UTC on 28 August (shaded) and wind field (streamlines) at 1100 m above surface.*

During the whole period, concentrations at 1100 m above the surface reached a maximum of 1150 ppb. The greater values were located near the emission sources. On 23 August (not shown) the smoke plume had a southward penetration between latitudes 25º S and 30º S and then turned towards the Atlantic Ocean, in agreement with the dominance of the anticyclonic system. The regional plume reached its southernmost position, between 1800 UTC on 24 August and 1200 UTC on 25 August, with a northwest-southeast orientation. During 25 August the plume had a relatively smaller latitudinal extent and on 26 August it became more northerly oriented. On 27 August started again to reach higher latitudes and extended farther than 40º S, until the end of the considered period. The final mean position was eastward of the previous one, due to the displacement of the frontal system.

The vertically integrated PM2.5 concentrations (mgm^{-2}) are illustrated in Figure 7. They reached a maximum value of 440 mgm^{-2} during the studied period. The pattern is very similar to that obtained for the CO mixing ratio. At 1200 UTC on 25 August the higher value was 180 mgm^{-2} and was located at 10º S. Paraguay, northern Argentina and southeastern Brazil had concentrations between 20 and 40 mgm^{-2}. At 1800 UTC on 28 August the columnar PM2.5 varied between 20 and 180 mgm^{-2}. Uruguay and southern Brazil had concentrations ranging from 40 to 60 mgm^{-2} whereas Paraguay and northern Argentina had values between 60 and 80 mgm^{-2}.

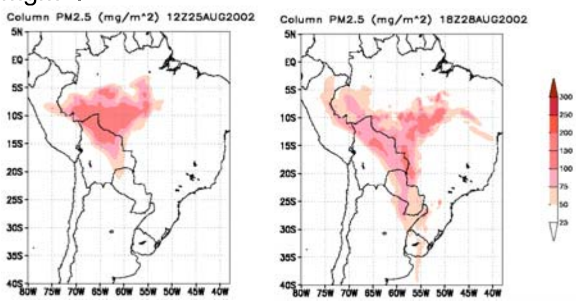


Figure 6: Vertically integrated PM2.5 mass concentration (mgm^{-2}) at 1200 UTC on 25 August and 1800 UTC on 28 August.

The regional transport of smoke is clearly shown. The smoke plume originated in the vegetation fires over tropical South America and was transported first westward, then deflected by the Andes barrier and finally southward, reaching mid-latitude regions farther south of 40º S. The cold front approach moved the polluted air mass towards southeastern Brazil and the Atlantic Ocean.

Vertical cross sections at latitudes 15 º S, 25º S and 35º S, across the smoke plume contribute to depict the distribution of CO (ppb) concentrations and the relationship with the main transport mechanisms. Figure 7 shows the obtained patterns. The vertical axis is the height (m) above the local surface.

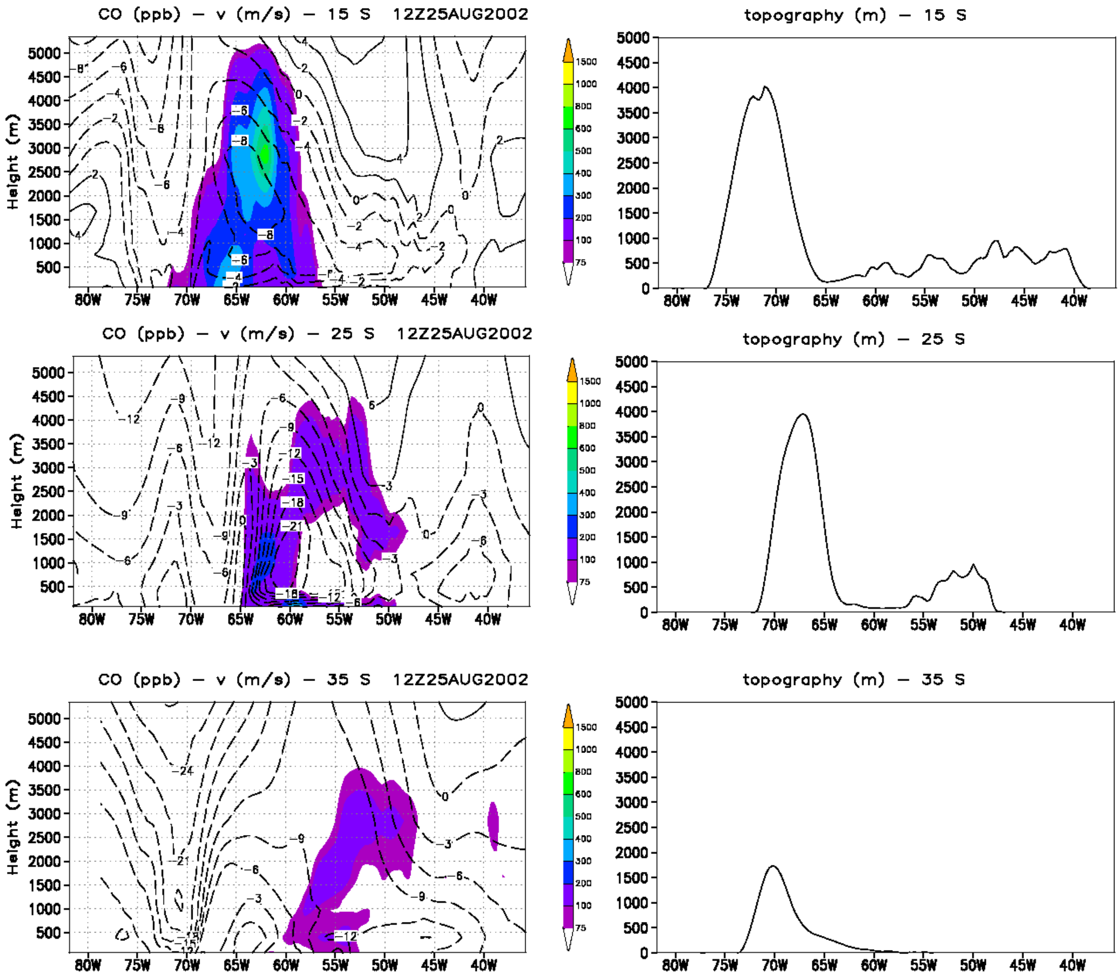


Figure 7: Vertical cross-sections at latitudes 15º S, 25º S and 35º S of CO (ppb) concentration (shaded) and meridional wind (ms^{-1}) (contour) against the height above surface (left panels). The terrain height profile is shown in the right panels.

In general, Figure 7 shows the higher concentrations near the emission sources.

The vertical cross-section at 15º S clearly illustrates the role of the LLJ as a transport mechanism. The maximum concentrations were located in the layer 2500-3000 m and the higher meridional wind (from the north) was relatively shallower. They were located around 62.5º W. CO mixing ratio reached values between 600 and 800 ppb. There was a secondary maximum near the surface.

At 25º S, both the LLJ core and the higher concentrations were located closer to the ground, between 500 and 1500 m at about 63º W. The meridional wind is stronger than that obtained at the lower latitude. The related CO mixing ratio showed values between 200 and 300 ppb. There was a small region with higher concentrations near the surface at 60º W. The presence of the CO plume at higher altitudes that extends eastward was due to the transport associated with the cold front incursion.

At the southernmost latitude, the CO mixing ratios varied between 75 and 300 ppb. The highest meridional wind was located just above the surface between 55º and 45º W.

4. SUMMARY

A study of the relationship of the South American Low Level Jet east of the Andes and the regional transport of biomass burning products was carried out. For a particular year, the simultaneous occurrence of the SALLJ and biomass burning was determined. The situations were simulated with the CAT-BRAMS modeling system. The detailed three-dimensional structure and evolution of the fields contributed to depict the preferred regions and levels in which the transport of the biomass burning products took place.

It is also possible to analyze the interactions with clouds or local circulation and the influence on forcing mechanisms. The predicted concentrations are compared with the observational data obtained from remote sensing and in-situ measurements at some sites. The comparisons of the model predictions and measurements are used to analyze the skill of the model.

This study is a first characterization to depict some features that should be further investigated. The analysis contributes to the evaluation of the impact of the biomass burning on a regional context as well as towards the control of the performance and improvement of the modeling system. In addition, the results may provide some guidelines to place observational sites to contribute to a better understanding as well as to document the atmospheric composition and assess the probable climate change impacts.

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