Moisture budget of the bimodal pattern of the summer circulation over South America

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Received 27 June 2001; revised 26 November 2001; accepted 18 December 2001; published 12 September 2002.

[1] Submonthly variations in warm-season (January–February) precipitation over South America, in particular over the Amazon basin, central southwest Brazil, north Argentina, and Paraguay are studied. Two distinct regimes of lower tropospheric winds (westerlies and easterlies) were observed in Rondonia during the Wet Season Atmospheric Mesoscale Campaign (WETAMC) component of the Large-Scale Atmosphere-Biosphere Experiment in Amazonia (LBA) and the Tropical Rainfall Measuring Mission (TRMM) field campaign. The westerly (easterly) winds were associated with strong (weak) convective activity over the South Atlantic Convergence Zone (SACZ). The period of this study (January and February of 1999) was divided into SACZ and no SACZ (NSACZ) regimes. The vertically integrated moisture fluxes over South America obtained from the National Aeronautics and Space Administration/Goddard Data Assimilation Office (NASA/DAO) assimilation system show that during the SACZ (NSACZ) period, strong (weak) convergence occurred over the Amazon basin with divergence (convergence) over southwestern Brazil, northern Argentina, and Paraguay. These moisture budgets also indicated that moisture transport from the tropics to the extratropics in the South American sector occurs more efficiently during the SACZ regime than during the NSACZ regime. *INDEX TERMS:* 3364 Meteorology and Atmospheric Dynamics: Synoptic-scale meteorology; 3374 Meteorology and Atmospheric Dynamics: Tropical meteorology; 3337 Meteorology and Atmospheric Dynamics: Numerical modeling and data assimilation

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

1. Introduction

[2] Moisture plays a key role in several aspects of human life such as water supplies for daily needs and agriculture. The water balance of the Amazon basin is of great importance, due to the presence of one of world's largest hydrographic system. The Amazon region is an important source of heat and water vapor for the atmosphere and plays a significant role in the general circulation of the atmosphere [e.g., *Garstang and Fitzjarrald*, 1999].

[3] There is increasing recognition of the importance of the role played by moisture transport from the Amazon basin to extratropical latitudes (Southern Brazil, Paraguay, and Northern Argentina). The central and southern Amazon exhibits the largest integrated moisture convergence, especially during summer. Most of the annual total rainfall over the region occurs during the austral summer (January–February). The tropical Atlantic region is the largest moisture source for the Amazon basin [*Marengo*, 1992]. Conversely, the Amazon region is a moisture source for other regions outside the Amazon [*Garreaud and Wallace*, 1998; *Liebmann et al.*, 1999; *Marengo*, 2000].

[4] Several authors have analyzed the variability of the summertime atmospheric circulation over subtropical South America from the viewpoint of seasonal to interdecadal timescales [e.g., *Liebmann et al.*, 1999; *Lenters and Cook*,

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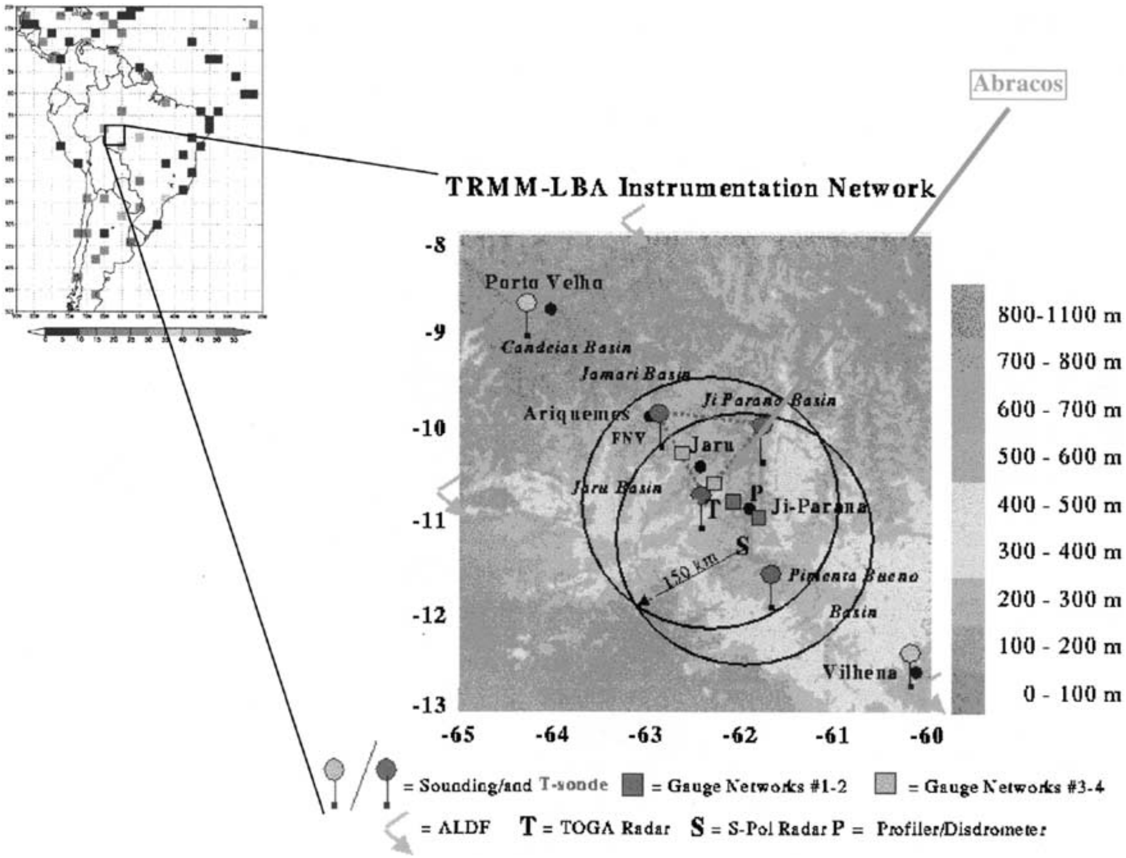

Figure 1. Map of South America with the experimental area in the State of Rondonia. The enhanced map shows the WETAMC/TRMM-LBA sites with the instrumentation deployed. The colorbar indicates the number of radiosondes that were used by GEOS-2 assimilation. Porto Velho (top of enhanced map) and Vilhena (bottom of enhanced map) were the closest stations to the WETAMC/TRMM-LBA region to be assimilated in GEOS-2. The shaded in the background denote land surface elevation (m).

1999; *Robertson and Mechoso*, 2000]. Relatively few studies have tried to understand the submontlhy variability and its three-dimensional structure and relationship to the large-scale circulation during the austral summer.

[5] The incursion of tropical air into the midlatitudes is linked to the circulations of the south Atlantic subtropical high and to the Chaco low, through their effect on the South American low-level jet (LLJ). Global analyses and some sparse observational data [*Berri and Inzunza*, 1993; *Douglas et al.*, 2000; *Marengo et al.*, 2002] suggest that there is a northerly LLJ to the east of the Andes mountains that contributes to the meridional moisture transport from the Amazon Basin into the subtropical regions of South America and modulates convective outbreaks in those regions. The South American LLJ has a structure similar to its North American counterpart [*Nogués-Paegle and Mo*, 1997; *Marengo et al.*, 2002]. Incursion of tropical air into midlatitudes occurs on the eastern side of the Andes in two preferred regions. The first is the narrow low-level jet that flows along the eastern slope of the Andes bringing warm and moist air from the Amazon basin to the Prata river basin (northern Argentina, Paraguay, and southern Brazil). The second is located farther eastward and is a function of the presence and position of the South Atlantic Convergence Zone (SACZ) [*Seluchi and Marengo*, 2000]; that is, it occurs only when the SACZ is present and it flows along the SACZ. The SACZ is a dominant summertime cloudiness feature of subtropical South America and adjacent South Atlantic Ocean. The SACZ is a cloud band that extends from the intense convection over the Amazon basin southeastward into the South Atlantic Ocean [*Kodama*, 1992, 1993; *Figueroa et al.*, 1995; *Nogués-Paegle and Mo*, 1997; *Liebmann et al.*, 1999; *Robertson and Mechoso*, 2000].

[6] The Wet Season Atmospheric Mesoscale Campaign (WETAMC) component of the Large-Scale Atmosphere-Biosphere Experiment in Amazonia (LBA) and the Tropical Rainfall Measuring Mission (TRMM) field campaign, known as TRMM/LBA, were conducted in the southwest corner of the Amazon basin during the wet season months of January and February 1999 (Figure 1). The goal of the field campaigns was to provide a detailed study of tropical convection in Amazonia, with its different impacts, as well as on the regional response to the larger scale forcing. Together, the WETAMC/LBA and TRMM/LBA campaigns represent an opportunity to study tropical convection in Amazonia and its relation to the underlying forested and deforested regions [*Silva Dias et al.*, 2000, 2002].

[7] Based on the ABRACOS site radiosondes, *Rickenbach et al.* [2002] identified alternating periods of low-level easterlies and westerlies in Rondonia during the WETAMC/TRMM-LBA experiment. They found that the low-level flow and precipitation organization in Rondonia were modu-

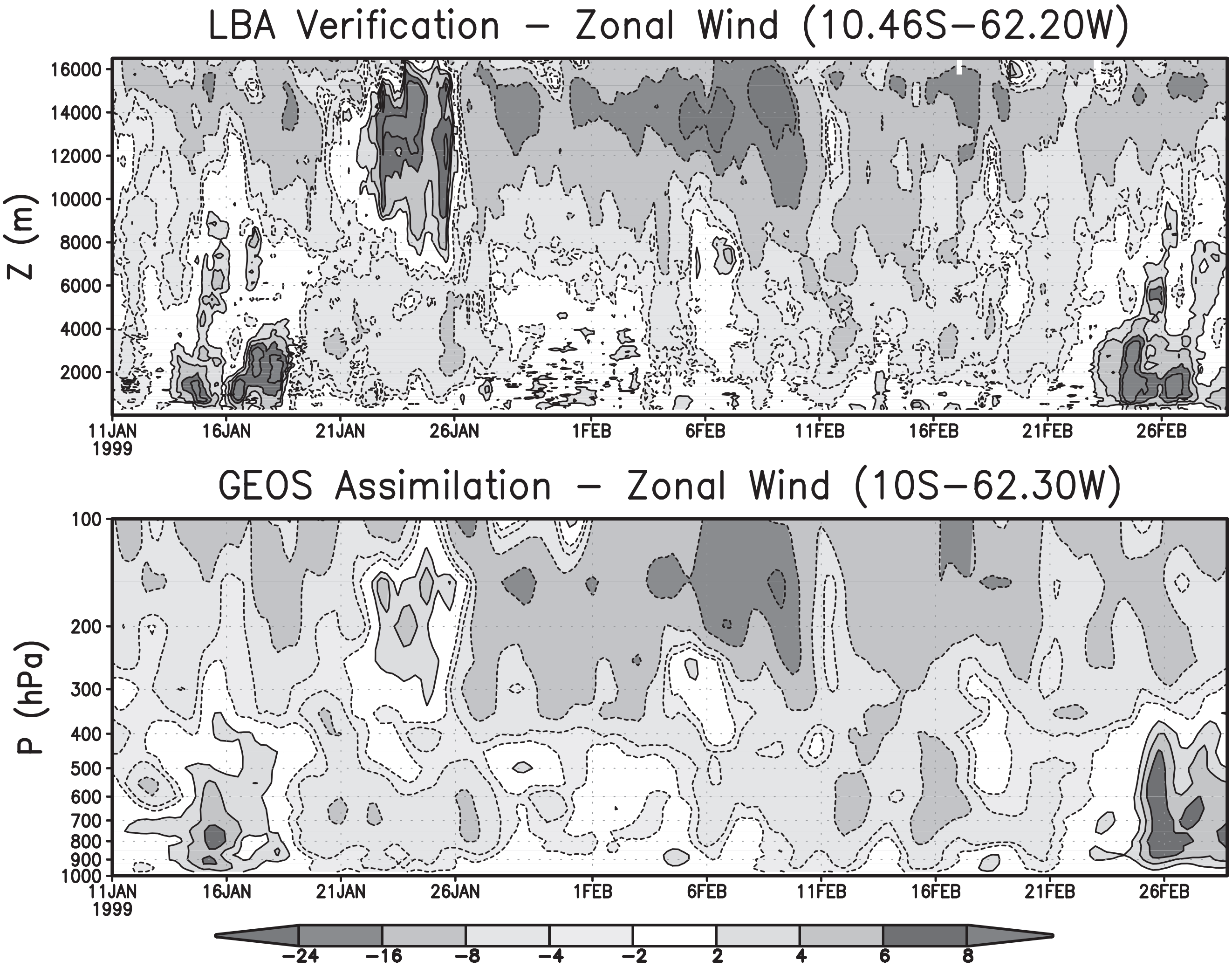

Figure 2. Time series of the zonal wind component observed at ABRACOS (10°46′S–62°20′W) site during WETAMC/LBA-TRMM campaign (January–February 1999) in Ji-Parana (a) and from GEOS-2 data set at 10°S–62°30′W (b). Units are m/s.

lated by the SACZ. In Rondonia the non-SACZ (NSACZ) period was characterized by low-level easterly winds and predominantly convective precipitation. The two SACZ periods observed during the WETAMC/TRMM-LBA were characterized in Rondonia as periods of low-level westerly flow and weaker, predominantly stratiform precipitation. The present study examines the differences in the continental scale moisture budgets between the two regimes.

[8] The accurate representation of the hydrological cycle is one of the most difficult data assimilation problems because the quality of the final assimilated data sets depends strongly on the quality of the observations, the ability of the system to ingest observations without shocking the hydrological component, and the veracity of the physical parameterizations [*Min and Schubert*, 1997]. Data assimilation has the potential for providing global estimates of all the hydrological cycle, more accurate and consistent than observations alone.

[9] The combined use of observations and modeling is a powerful tool for understanding the moisture budget in this region and improve the simulation and seasonal prediction of climate anomalies. In this paper, we examine the moisture transport associated with the bimodal pattern of the summer circulation over South America. Section 2 describes the data sets used in this study (DAO/NASA analysis and WETAMC/TRMM-LBA campaign radiosondes) and reviews the rationale for dividing the WETAMC/TRMM-LBA campaign period into two separate regimes and the data sets used in this study. Section 3 identifies the main pathways of moisture flow during the different regimes of the bimodal pattern of the circulation observed over South America during the WETAMC/TRMM-LBA campaign. Results are discussed and summarized in section 4.

2. Data and Methodology

[10] Four times daily analyses of wind, specific humidity and moisture flux were obtained from the Data Assimilation Office (DAO) at the National Aeronautic and Space Administration (NASA) Goddard Space Flight Center for January and February 1999. For this study we use version 2 of the Goddard Earth Observing System (GEOS-2) Data Assimilation System (DAS). This system addresses many of the

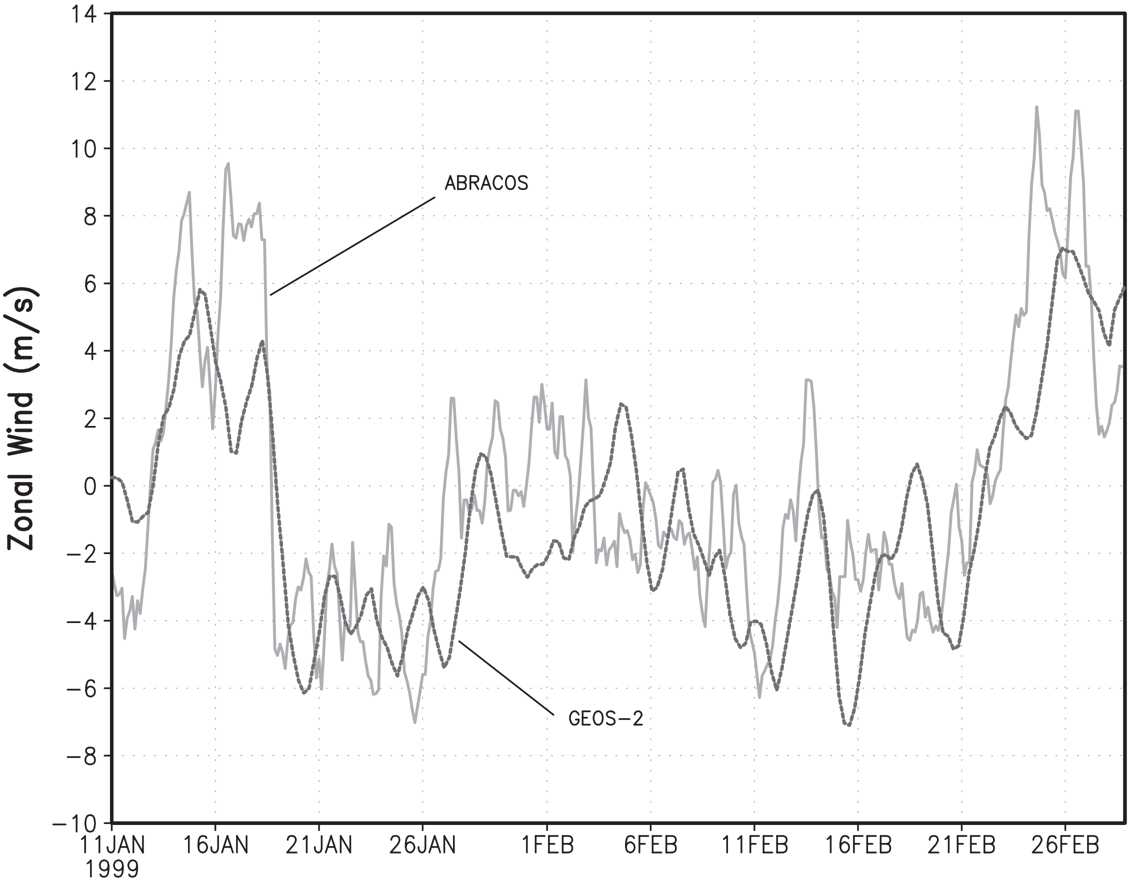

Figure 3. Time series of the zonal wind component at 850 hPa during WETAMC/LBA-TRMM campaign for ABRACOS at 10°46′S–62°20′W (solid line), GEOS-2 data set at 10°S–62°30′W (dashed line). Units are m/s.

shortcomings in GEOS-1 DAS [*Schubert et al.*, 1993], including improved vertical resolution and a global Physical-space Statistical Analysis System (PSAS). A detailed description of GEOS-2 is given in *DAO* [1996] and *Chen et al.* [1999]. The global data are available on a horizontal resolution of 2.0° × 2.5° latitude-longitude grid at 28 pressure levels. For the purposes of this study, the geographic domain is restricted to South America (20°N–50°S, 90°W–20°W).

[11] Figure 1 depicts the enhanced WETAMC/TRMM-LBA experimental area in the State of Rondonia. The top panel shows the GTS (Global Telecommunication System) sites where radiosonde data is available on a routine basis to be assimilated into a global model. The colorbar indicates the number of radiosondes that were used by GEOS-2 assimilation in January of 1999. Similar radiosonde density was used in the February 1999 assimilation. Porto Velho (top of enhanced map) and Vilhena (bottom of enhanced map) were the closest stations to the WETAMC/TRMM-LBA region to be assimilated in GEOS-2. The sounding data from ABRACOS (10°46′S–62°20′W, 290 MSL) were used as independent verification of the GEOS-2 assimilation, which did not include the WETAMC/TRMM-LBA field campaign data. The quality of the reanalysis data set has been shown to be adequate in several studies of tropical and subtropical intraseasonal variability [*Mo and Higgins*, 1996; *Min and Schubert*, 1997; *Nogués-Paegle et al.*, 1998; *Liebmann et al.*, 1999; *Shay-El et al.*, 1999].

[12] The site of ABRACOS was chosen because it represents the longest intensive observing period during WETAMC/TRMM-LBA campaign. The radiosondes were launched at approximately three-hour intervals, for the period from 9 January until 28 February 1999 [*Silva Dias et al.*, 2000]. A total of 317 soundings were used in this study.

[13] Daily Outgoing Longwave Radiation (OLR) from NOAA-CIRES/Climate Diagnostics Center (CDC) is used as proxies of tropical convection. This data set has been interpolated to remove gaps due to missing values. The daily values represent averages of the day and night passes of the polar-orbiting satellites [*Liebmann and Smith*, 1996].

2.1. SACZ and NSACZ Events

[14] Figure 2a shows the time series of the zonal wind observed during WETAMC/TRMM-LBA campaign based on soundings from ABRACOS-Rondonia (10°46′S–62°20′W). It was constructed by applying a 5-point running mean filter to 3-hourly sounding data. During the third week of January low-level winds were predominantly from the west shifting to easterlies after 19 January and returning to westerlies after 22 February. Figure 2b shows the time series of the zonal wind component from GEOS-2 DAS (Data

Assimilation System) analysis from 11 January through 28 February at the grid point (10°S–62°30′W) near ABRACOS-Rondonia. The DAO time series, also constructed by applying a 5-point running mean filter to 6-hourly data, is also shown in Figure 2b. Although the peak winds are sub estimated by the DAO analysis, the general patterns are in good agreement with the ABRACOS radiosonde time series, clearly showing the dominant low-level westerly winds during the third week of January and the last week of February and even the period of very weak westerlies between 29 January and 8 February. The agreement between the observed data and DAO/NASA fields suggest that the assimilation products can be useful for studying these events.

[15] The similarity between the observed data and DAO/NASA analysis becomes clearer in Figure 3, which shows the zonal winds at 850 hPa. Two major and one minor westerly wind episodes were characterized by a deep layer of westerly winds extending from the surface to at least 400 hPa [*Rickenbach et al.*, 2002]. The first major westerly wind episode began on 14 January through 18 January. Following *Rickenbach et al.* [2002] the minor westerly wind episode that began on 29 January and ended on 8 February, is considered part of the easterly period for compositing purposes. The second major westerly wind episode occurred from 22 February through 28 February. The interim periods were defined as easterly (or NSACZ) regimes.

[16] Composites of the OLR averaged over 14–18 January, 19 January through 21 February, and over 22–28 February, during the WETAMC/TRMM-LBA are shown in Figures 4a, 4b, and 4c, respectively. As expected, the average over the first low-level westerly period is characterized by strong convective activity over central tropical South America (Figure 4a). The convection extends southeastward into the South Atlantic Ocean in a pattern that is characteristic of SACZ events. Figure 4b shows that the period between 19 January and 21 February featured much less deep convection, especially over southeastern Brazil where the SACZ is not as well organized as in the earlier period. The second westerly period (Figure 4c) featured convective activity strong enough to characterize a well-defined SACZ that extended from central Brazil southeastward across southeastern Brazil and the adjoining Atlantic Ocean.

[17] The above results suggest that the variability of the zonal wind component in low-levels at ABRACOS, confirmed by analysis from GEOS-2 DAS and composites of the OLR, can be separated into two distinct regimes: (1) the SACZ periods that occurred during the third week of January and last week of February and (2) a no SACZ (NSACZ) period that took place during the last two weeks of January until mid February. With the purpose of simplifying the results and analysis, the whole period (January and February) was divided into the two distinct regimes of SACZ and NSACZ. The composite moisture budgets for each regime are shown in the next section.

3. Moisture Budget

[18] The vertically integrated moisture transport during the SACZ and NSACZ regimes defined in section 2 were calculated using the GEOS-2 DAS analysis. Intense mois-

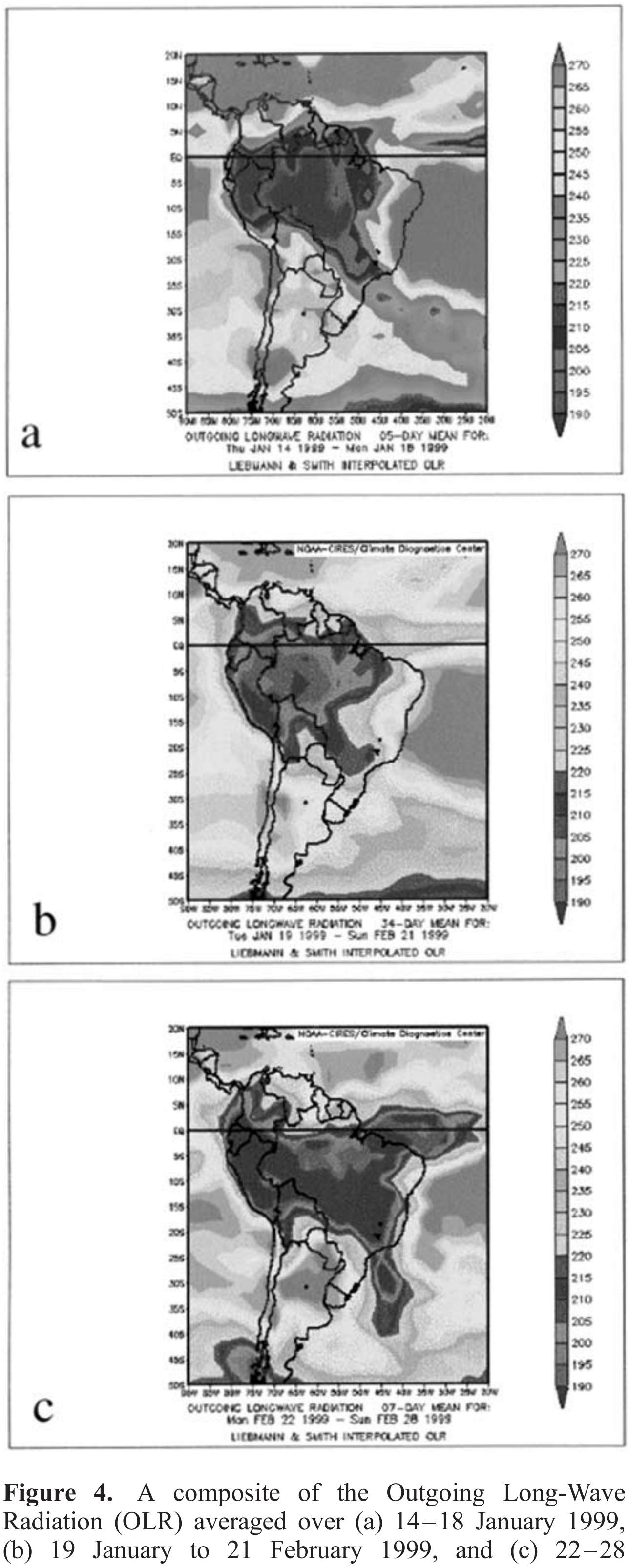

Figure 4. A composite of the Outgoing Long-Wave Radiation (OLR) averaged over (a) 14–18 January 1999, (b) 19 January to 21 February 1999, and (c) 22–28 February 1999, during the WETAMC/TRMM-LBA. Image provided by the NOAA-CIRES Climate Diagnostics Center, Boulder, Colorado, USA, from their Web site at http://www.cdc.noaa.gov/. Units are W/m^2.

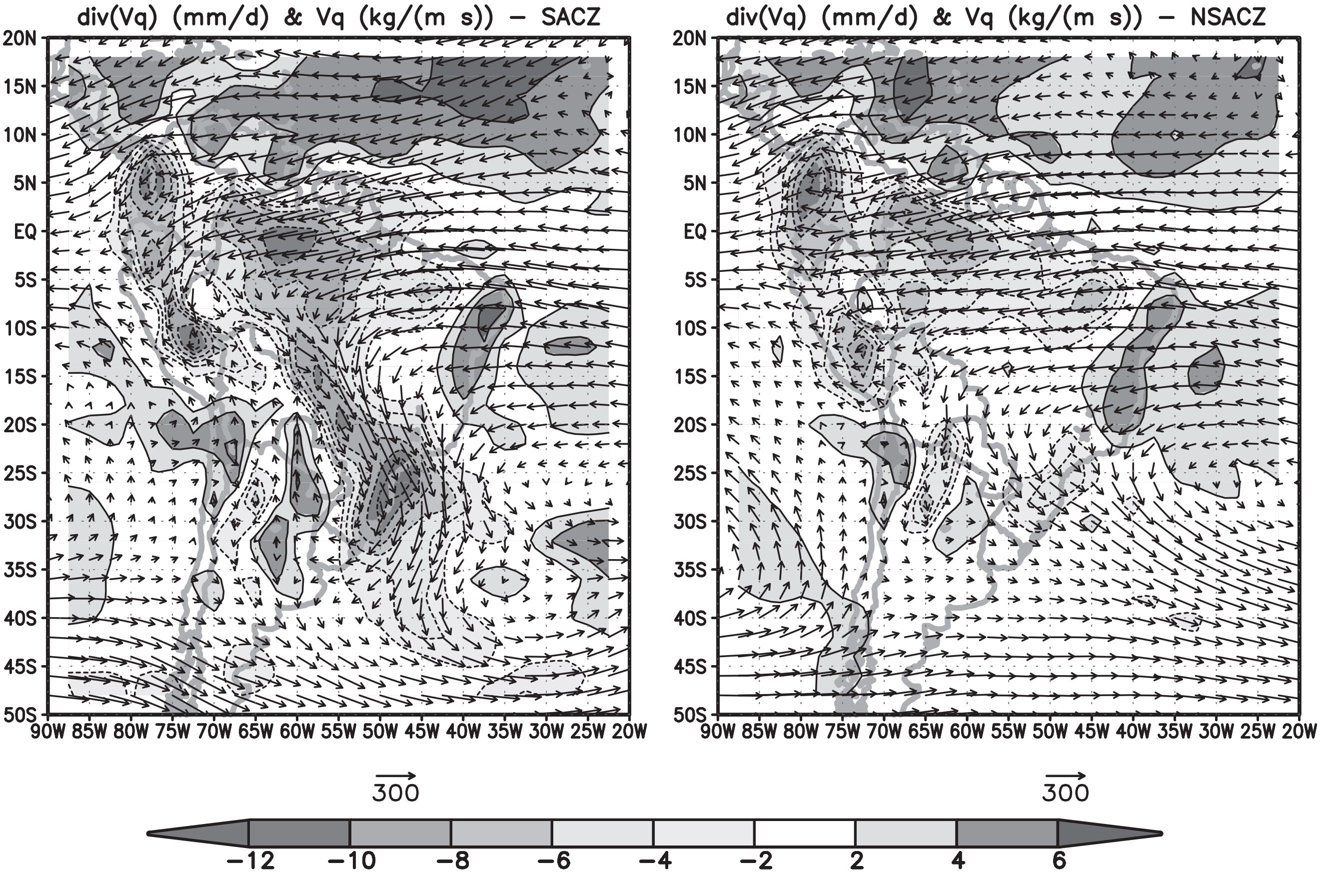

Figure 5. Vertically integrated regional moisture flux (vectors) and moisture flux divergence (shaded) for (a) SACZ period and (b) NSACZ period from GEOS-2 data set. The units for vectors is kg/(ms) and divergence in units of mm/day.

ture flux convergence over the Amazon basin and over southeast and central Brazil characterize the SACZ regime. This convergence extends over the adjacent South Atlantic Ocean (Figure 5), in a pattern that closely follows the SACZ convection seen in Figures 4a and 4c. Divergence can be observed over eastern Brazil, northwestern Argentina, Paraguay, southern Bolivia, and northern Chile. The NSACZ period is characterized by weaker convergence over Amazonia, southeast and central Brazil, and convergence in Paraguay and northern Argentina.

[19] Figure 5a indicates the reversal of the climatological northerly moisture flux over northern Argentina and Paraguay to southerly during the SACZ regime. This is due to the presence of an anomalous cyclonic circulation between 20° and 25°S, which is predominant during the SACZ regime. Another flow reversal occurred over western central Amazon (near 10°S–60°W) with the presence of westerlies during the SACZ regime and easterlies during the NSACZ regime. Moreover, during the SACZ regime the trade winds display a stronger northern component over the northern Amazon characterizing an intensification of moisture transport from the tropics to the extratropics.

[20] Figure 6 displays the vertical cross section of the mean moisture flux during the SACZ (Figure 6a) and NSACZ (Figure 6b) events at 18°S. It is clear from Figure 6 that the vertically integrated moisture fluxes and convergence shown in Figure 5 are primarily accomplished at low levels. During the SACZ regime a strong low-level jet brings warm and moist tropical air from the Atlantic Ocean and Amazon region to the subtropics producing intense convection in central, southeast, and western Brazil. During the NSACZ regime the maximum northerly flux (Figure 6a) is weaker and displaced westward and closer to the Andes Mountains than during the SACZ regime (Figure 6b). As a result of this shift of the low-level jet moisture supply for the SACZ region is cut off and shifted westward to fuel convection in midlatitude South America, namely northern Argentina, Paraguay, and southern Brazil - Prata Basin (Figure 5b). *Figueroa et al.* [1995] and *Gandu and Geisler* [1991] have previously studied the channeling of the low-level flow by the Andes mountains during wet season.

[21] There is a strong correlation between winds and specific humidity over Northern Argentina/Paraguay (hereafter referred to as Plains) and the WETAMC/TRMM-LBA region. The period of westerlies (easterlies) flow over the Amazon region coincides with the southerly (northerly) flow over the Plains. Specific humidity over the Plains is lower during the southerly events (not showed). The period of southerly flow over the Plains coincides with the SACZ regime. Northerly flow occurs during the NSACZ regime. *Nogués-Paegle and Mo* [1997] show that when the SACZ is enhanced there is a weakening of the moisture transport to northern Argentina, Paraguay and south/southeastern Brazil. On the other hand, the weakening of the SACZ (NSACZ)

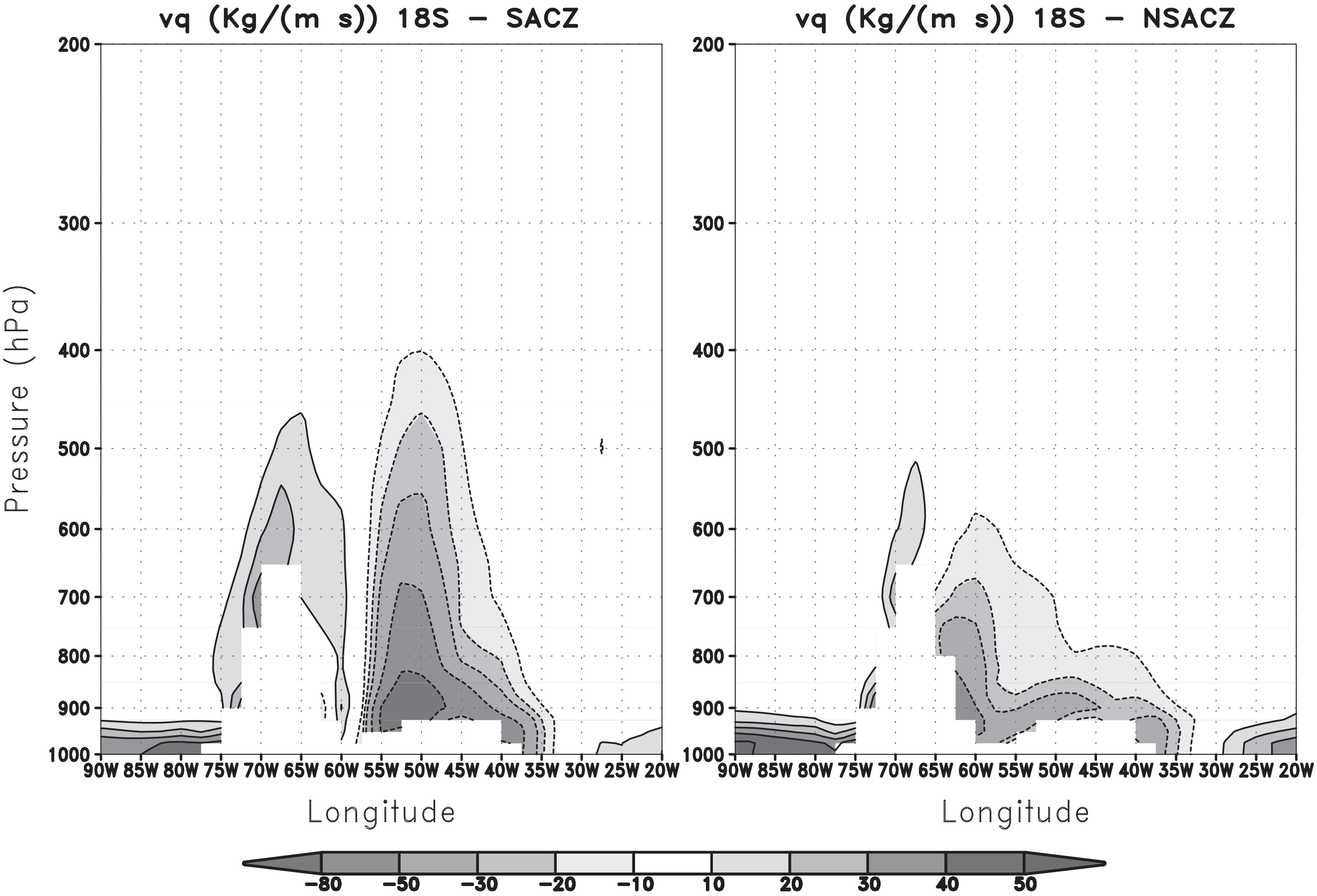

Figure 6. Vertical cross section of the mean moisture flux divergence along latitude 18°S, calculated from GEOS-2 data set. SACZ (a) and NSACZ (b). A shading bar, in units of (g/kg)/(m/s), is at bottom of the figure.

regime is associated with the reinforcement of moisture transport to north Argentina, Paraguay and south/southeast of Brazil, with important consequences for the hydrological balance over the Prata Basin. *Silva Dias* [2000] used the RAMS mesoscale model and found similar results with intense low-level jet along the eastern slopes of the Andes mountains during the time of NSACZ event (18–22 January, 27–28 January, 30 January until 3 February, and 11–14 February).

3.1. Moisture Transport Between Tropics and Extratropics

[22] The complex large-scale moisture transport over the tropics and extratropics, which was discussed in the previous sections, is summarized in Figure 7. This figure displays the vertically integrated moisture fluxes and budgets over South America for the SACZ and NSACZ regimes. This is further illustrated in Table 1, which summarizes the integrated moisture flux divergence over the South America boxes, based on GEOS-2 analysis. All values are area weighted and units are scaled to mm/day. The strongest moisture inflow for South America is from the Atlantic Ocean (box D) for both regimes. This inflow is comparable for the two regimes with 18.7 mm/day during the SACZ (Figure 7a) and 17.9 mm/day during NSACZ (Figure 7b). The stronger outflow is to the South Atlantic Ocean (12.7 mm/day) during the SACZ regime (box F), and to Peru and the Eastern Pacific Ocean during the NSACZ regime (box A). This suggests that the most efficient transfer of moisture from the tropics to the extratropics in the South American sector is accomplished during times when the SACZ is present.

[23] During the SACZ regime (Figure 7a) strong moisture convergence occurred over the Amazon region (7.8 mm/day in box A and 3.9 mm/day in box D) and central and southeastern Brazil (3.9 mm/day in box B and 7.0 mm/day in box F, respectively). The strongest inflow into South America was from the tropical Atlantic into the Amazon basin. From there, moisture was funneled southward passing through boxes B and E and into the region of strong convergence in southeastern Brazil (box F). The moisture flow pathway described above is characteristic of the SACZ regime. Note how there is good agreement between the regions of strong moisture convergence calculated by the NASA/DAO GEOS 2 analysis and the regions of enhanced convection in Figures 4a and 4c. This provides additional evidence of the good quality of the NASA/DAO GEOS 2 analysis.

[24] During the NSACZ regime two main pathways of moisture transport were present. In the first one, airflowed from the equatorial Atlantic ocean into the Amazon basin and then westward toward Peru, the Andes and into the

Eastern Pacific Ocean. Moisture convergence in the western Amazon basin (box A) is weaker during the NSACZ period than during the SACZ period. The OLR composites shown in Figure 4 indicate that convective activity is also weaker in that region during the NSACZ than during the SACZ period. The second pathway of moisture during the NSACZ period has moisture from the Atlantic Ocean entering central Brazil (boxes B and E) and flowing southward into boxes C and F. Moisture convergence occurs in boxes C (1.4 mm/day) and *F* (1.1 mm/day).

[25] Convergence was stronger in almost all of the boxes during the SACZ regime when compared the NSACZ regime. In the Plains region, or box C, convergence was enhanced during the NSACZ regime. In boxes A, B, and F, on the other hand, convergence was twice, eight times, and six times stronger, respectively, during the SACZ regime than during the NSACZ regime. Another remarkable feature is the moisture flow reversal that occurred between the two regimes at the southernmost boundary of box B. Southerly moisture flow prevails during the SACZ period due to the presence of the anomalous cyclonic circulation over Paraguay. The enhanced northerly flow that occurs during the NSACZ regime is evidence of the moisture transport from the Amazon region to the Plains region, is associated to the low-level jet along the eastern slopes of the Andes.

Table 1. Integrated Moisture Flux Divergence Over the Regions Depicted by the Rectangle in Figure 7 for the SACZ and NSACZ Regimes[a]

	Boxes					
	A	B	C	D	E	F
SACZ	−7.8	−3.9	0.3	−3.9	−0.4	−7.0
NSACZ	−4.9	0.5	−1.4	−3.6	1.4	−1.1

[a] Units are in millimeters per day.

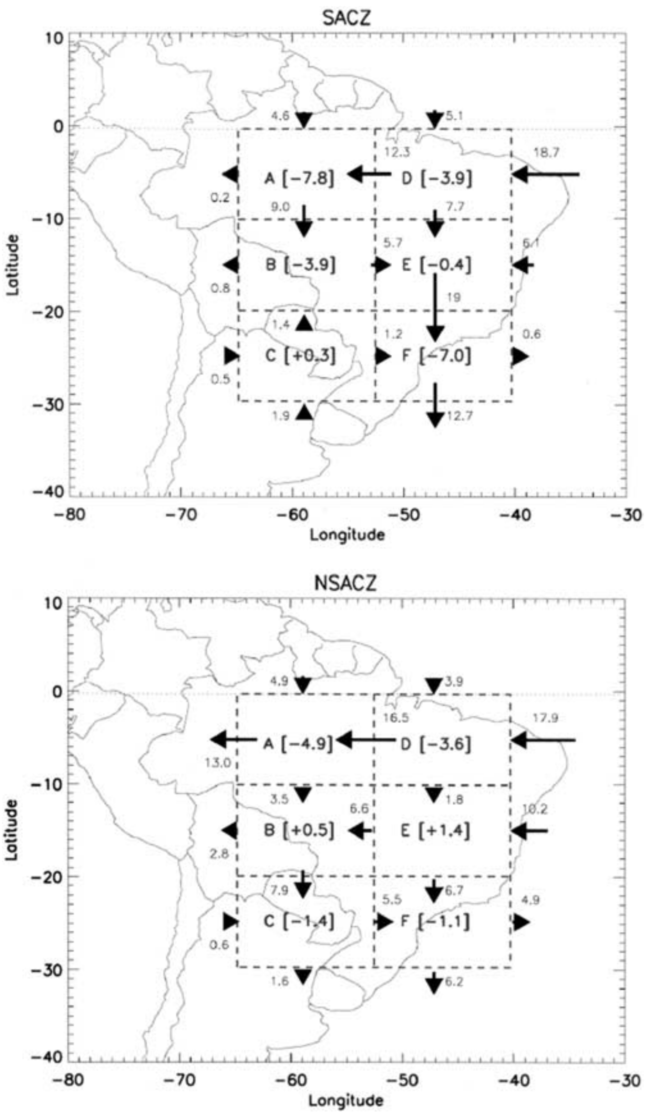

Figure 7. Vertically integrated moisture fluxes across the lateral boundaries and the area averaged vertically integrated moisture flux convergence over the South America region for (a) SACZ and (b) NSACZ period using GEOS-2 data set. Units are mm/day.

[26] In summary, very different pathways of moisture flow occur during the SACZ and NSACZ regimes. Stronger inflow of tropical moisture into the extratropics occurs during the SACZ than during the NSACZ regime. Moreover, during the SACZ regime the low-level jet is stronger and positioned farther eastward than during the NSACZ regime. This translates into a more concentrated moisture flow and convergence near southeast Brazil fueling the convection that is associated with the SACZ.

4. Summary and Conclusions

[27] This study has documented the moisture budget of the bimodal pattern of the summer circulation over South America using the NASA/DAO GEOS 2 analysis. During the SACZ regime, low-level westerly winds over the central Amazon were accompanied by convergence over central Amazonia and over central, southeast, and western Brazil. In contrast, during the NSACZ regime easterlies were dominant over the central Amazon, and divergence occurred over central and western Brazil with enhanced convergence over the subtropical Plains region.

[28] The Plains region has frequently been characterized as a net atmospheric moisture sink during summertime [*Saulo et al.*, 2000]. However, when the SACZ is present this region (Figure 7a) can be classified as a net moisture source. During the SACZ regime the total moisture flux convergence over this region is negative (−0.3 mm/day) indicating weak outflow or divergence. In agreement with the results obtained by *Nogués-Paegle and Mo* [1997], we have found suppressed precipitation over the Plains region during the SACZ regime. During the NSACZ regime, there is enhanced moisture transport to the Plains region (7.9 mm/day) from the north and a net inflow of 1.4 mm/day. *Robertson and Mechoso* [2000] have shown that the Parana/Paraguay rivers (extending northward to near 15°S) are directly influenced by the SACZ and tend to swell during SACZ events. The Uruguay/Negro rivers (25°−35°S) to the south are influenced in the opposite sense through the dipole in vertical motion and possibly by accompanying variations in southward moisture transport by the LLJ east of the Andes.

[29] The main characteristic over the Plains (box C) is the inversion of the moisture flux in north-south boundaries

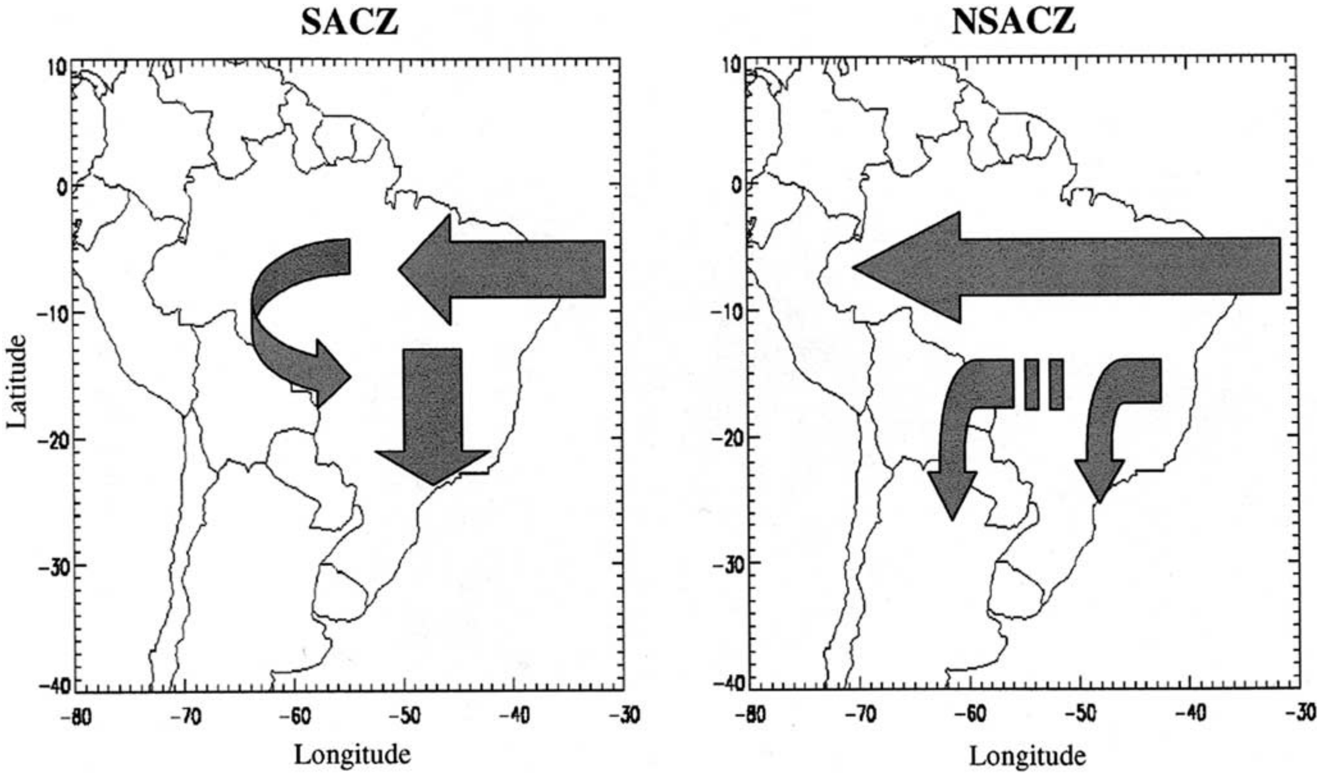

Figure 8. A conceptual diagram of the different pathways of moisture flow documented for the SACZ and NSACZ regime periods that occurred during the WETAMC/TRMM-LBA campaign.

from SACZ event to NSACZ event. This is in agreement with the results of *Min and Schubert* [1997] who compared different assimilation products over this region for two selected extreme climate (drought and flood) events. Our vertically integrated moisture flux over the Plains region for the SACZ (NSACZ) regimes have the same characteristics as the drought (flood) events in their study. It is important to note that the enhanced inflow from north, during the NSACZ regime, results in an enhanced outflow at the east boundary (5.5 mm/day) contributing to the moisture budget over southern Brazil.

[30] A conceptual diagram of the different pathways of moisture flow documented for the SACZ and NSACZ regime periods that occurred during the WETAMC/TRMM-LBA campaign is shown in Figure 8. During the SACZ regime strong moisture flow from the Atlantic Ocean entered South America and was funneled into a narrow and strong southeastward current to southeast Brazil and to the Atlantic ocean. Strong convergence occurred in the Amazon basin and in central western Brazil and southeastern Brazil. During the NSACZ regime, on the other hand, there were two main pathways of moisture transport over South America. The first pathway involved westward transport of moisture from the equatorial Atlantic Ocean, passing through the Amazon basin, and on toward Peru and the equatorial Eastern Pacific Ocean. The second pathway involved inflow of Atlantic Ocean moisture into central Brazil and then a broad southward flow toward the Plains region and southeastern Brazil.

[31] South America is one of the most important regions in the Southern Hemisphere where moisture transport from the tropics to the extratropics occurs [*Newell et al.*, 1992]. The SACZ regime proved more efficient than the NSACZ regime in transporting tropical moisture into the extratropics. During the SACZ regime, not only the northerly moisture flow over most of Brazil was stronger, but also it originated deeper into the tropics than during the NSACZ regime. During the SACZ regime the low-level jet was stronger and positioned farther eastward than during the NSACZ regime. This translated into a more concentrated moisture flow and stronger convergence near southeast Brazil fueling the convection that is associated with the SACZ. Whether or not this conceptual model of moisture flux pathways for the bimodal pattern of South America summer circulation can be applied over longer periods remains to be studied.

[32] **Acknowledgments.** This project was in part funded by The State of São Paulo Research Foundation (FAPESP) and the Brazilian Council for the Development of Research (CNPq). D.L. Herdies acknowledges a Coordination of Training of Higher Education Graduate (CAPES) scholarship. This work constitutes part of D.L. Herdies' Ph.D. dissertation at University of São Paulo (USP). It is a pleasure to acknowledge the support of this work by Dr. Keneth Bergman, manager of Global Modeling and Analysis Program.

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