

# **DROUGHT IN BRAZIL DURING SUMMER AND FALL 2001 AND ASSOCIATED ATMOSPHERIC CIRCULATION FEATURES**

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## **Abstract**

A deficiência de chuvas no verão e outono de 2001 causou uma redução na vazão das bacias da região nordeste, centro-oeste e sudeste do Brasil, que se refletiu na geração de energia elétrica para essas regiões. A situação das hidroelétricas ficou crítica e a população entrou em regime de economia de energia seguindo um programa elaborado pelo governo para evitar uma situação de ausência total de energia. Neste artigo são discutidos os principais aspectos meteorológicos que foram responsáveis pela diminuição das chuvas nas regiões das bacias, principalmente no verão. A ocorrência da estiagem na região Sudeste no verão e outono de 2001 foi associada às influências dos VCAN, que atuaram com maior frequência e de maneira anômala sobre o continente, às influências de trens de onda associados ao padrão PSA, forçados pela intensa atividade convectiva na região da Indonésia e às Oscilações de Madden and Julian. A partir de maio a situação começou a se normalizar e as condições nas bacias em junho foram estáveis. Na época de inverno as chuvas são geralmente de pequena intensidade na região Sudeste do Brasil, associadas a passagens de sistemas frontais, e os níveis dos reservatórios de água continuaram baixos em JJA 2001.

## **1. Introduction**

Rainfall deficits during summer and fall 2001 resulted in a significant reduction in riverflow throughout Northeast, Central-West and Southeast Brazil, thereby reducing the capacity to produce hydroelectric power in these areas. The large-scale nature of the deficits, affecting nearly the entire country, resulted in an energy crisis that forced the government to impose energy conservation measures in order to avoid total loss of power (blackouts).

Climatologically, summer is the peak of the rainy season in the regions of Southeast, Central-West and southern Northeast (Bahia) Brazil. However, beginning in January 2001 large rainfall deficits developed throughout these regions, with drier than normal conditions worsening through the end of summer and into fall. At the same time, southern Brazil registered above-normal precipitation and occasional flooding.

The northern half of Northeast Brazil has a relatively short rainy season beginning in February and ending in May. Drier-than-normal conditions also dominated many

sections of the northern Northeast, with the exception of extreme northern coastal sections where above-normal precipitation was observed.

Some synoptic features that have been linked to rainfall variability over eastern and central Brazil include: 1) the Intertropical Convergence Zone (Northeast), 2) squall lines that form in association with the sea breeze (northern Northeast), 3) upper-level lows (Northeast and Southeast), and 4) Southern Hemisphere cold fronts/ South Atlantic Convergence Zone (Southeast, Northeast and Central-West). Intraseasonal and interannual variability in convective activity is modulated by the Madden-Julian (30-60 day) oscillation (MJO) and by the El Niño-Southern Oscillation (ENSO) cycle, respectively, especially over the northeastern third of the country. A description of these circulation features and their impacts on rainfall can be found in *Climanálise Especial- Edição Comemorativa de 10 anos (1996)*.

The main objective of this paper is to describe circulation features associated with the large-scale rainfall deficits observed in Brazil during the summer and fall 2000-2001 (December – May).

## **2. Precipitation and atmospheric circulation anomalies**

Our analysis of precipitation is based on daily observations available on the Global Telecommunications System (GTS) and on additional data available in CPTEC's data bank. Atmospheric circulation data are taken from the Climate Data Assimilation System (CDAS) of the National Centers for Environmental Prediction (NCEP).

The average precipitation over Brazil and the upper-tropospheric circulation pattern over South America for December-February and March-May are shown in Fig. 1. A characteristic feature of the precipitation pattern during December-February is the northwest-southeast oriented band of maximum precipitation that extends from the Amazon basin to the Southeast Brazil coast. This band and its extension over the neighboring Atlantic Ocean, is commonly referred to as the South Atlantic Convergence Zone (SACZ). At upper-tropospheric levels, large-scale anticyclonic flow dominates most of Brazil, with the center of circulation near Bolivia. This feature, known as the Bolivian High, represents the dynamical/ thermodynamical response of the atmosphere to intense summertime heating over the continent. The main axis of precipitation shifts northward and the Bolivian High weakens during March-May, as the rainy season ends over Southeast and Central-West Brazil.

Precipitation deficits were observed throughout Amazonia in December 2000 and over the Southeast and Central-West in January and February (Fig. 2). Several upper-tropospheric cyclonic vortices (vórtice ciclônico de altos níveis - VCAN) moved westward from the eastern South Atlantic to interior sections of Brazil during January and February. Since mid-tropospheric sinking motion characterizes these systems, they usually tend to suppress deep convection within five degrees of latitude/ longitude from the center. The greater-than-normal frequency of occurrence and deeper penetration into the continent of these vortices resulted in large-scale upper-tropospheric cyclonic circulation anomalies over central Brazil (Fig. 2), associated with a weaker than normal Bolivian High. Another contributing factor to the dryness in the region was a lack of significant cold fronts reaching Southeast Brazil. During January-February 2001 cold fronts managed to reach only as far north as southern Brazil, where rainfall was above normal.

Normally, VCANs remain close to the east coast of Northeast Brazil. However, in January 2001 these vortices moved gradually westward, reaching as far inland as the Brazil-Bolivia border and affecting the convection over much of Central-West and Southeast Brazil. The daily analyses of the upper-level flow for January (Fig. 3) show that four VCAN affected Brazil during the month. On January 1-2 it is still possible to identify the anticyclonic circulation associated with the Bolivian High and a VCAN, which was located along the Northeast coast near 10°S. The VCAN moved inland on 3 January and eventually reached the southern Amazon basin during 6-7 January. On 8 January another VCAN began to form in the vicinity of the Southeast coast. This system remained along the coast through 13 January and then moved westward during 14-20 January, reaching the Central-West region of Brazil. On 23 January this system is still identifiable in the analyses, while another VCAN began to develop near the Northeast coast. This new system also moved westward, reaching the eastern Amazon on 26 January. On January 28 the fourth VCAN of the month formed over the Northeast, and subsequently drifted slowly southward through 31 January. The VCANs continued to be active during February (not shown), as the overall pattern of cyclonic anomalies over central Brazil (Fig. 2) and lack of cold fronts in the Southeast persisted.

The pattern of anomalous upper-tropospheric cyclonic circulation over central Brazil and strong easterly anomalies over the Southeast was also observed in March, while precipitation deficits were observed over the eastern Amazon (Fig. 4). These circulation features continued into April before finally weakening in May. Rainfall deficits continued to be observed in the Southeast and Central-West during April, which typically marks the end of the wet season in those regions. As noted above, the anomalously dry months were accompanied by anomalous easterlies in the upper troposphere over the Southeast and by cyclonic circulation anomalies over central Brazil, representing a weaker-than-normal or displaced from normal Bolivian High. By May, normally the beginning of the dry season in the Southeast and Central-West, circulation features began to return to near normal over Brazil.

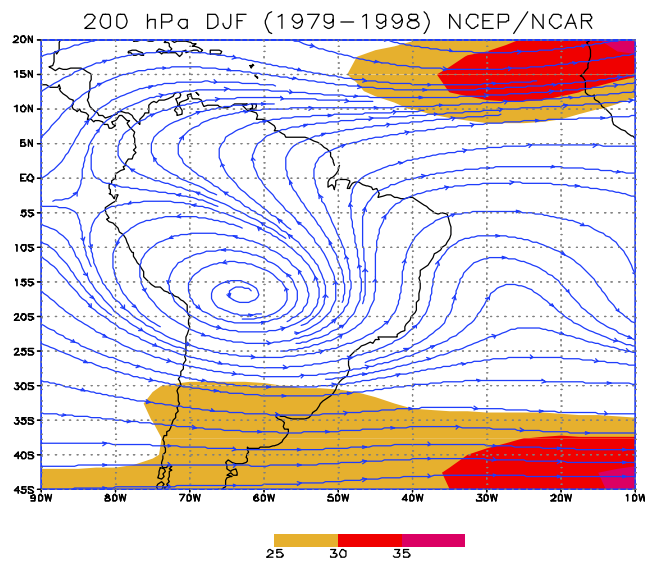
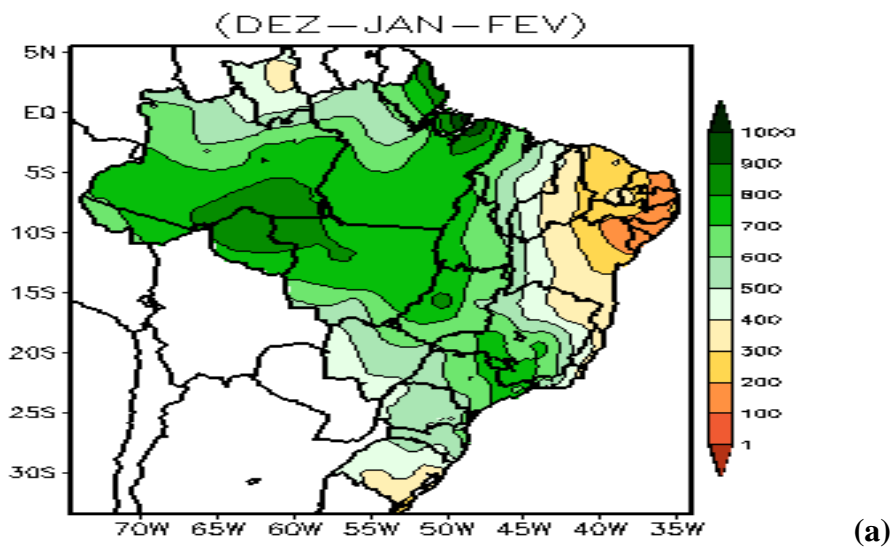


Fig. 1. Climatological precipitation over Brazil in a) DJF and c) MAM (1961-2000) from INMET dataset, regional centers and automatic stations (PCDs). Climatological wind flow at 200 hPa from NCEP/NCAR reanalyses dataset in b) DJF and d) MAM (1979-1997).

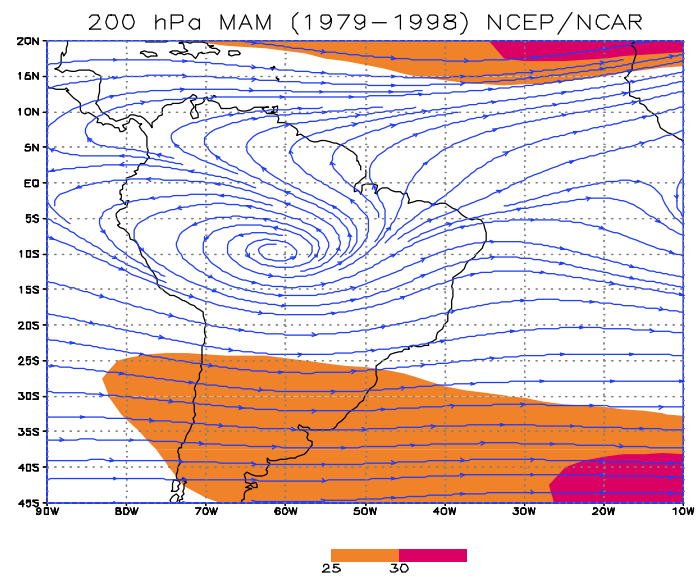
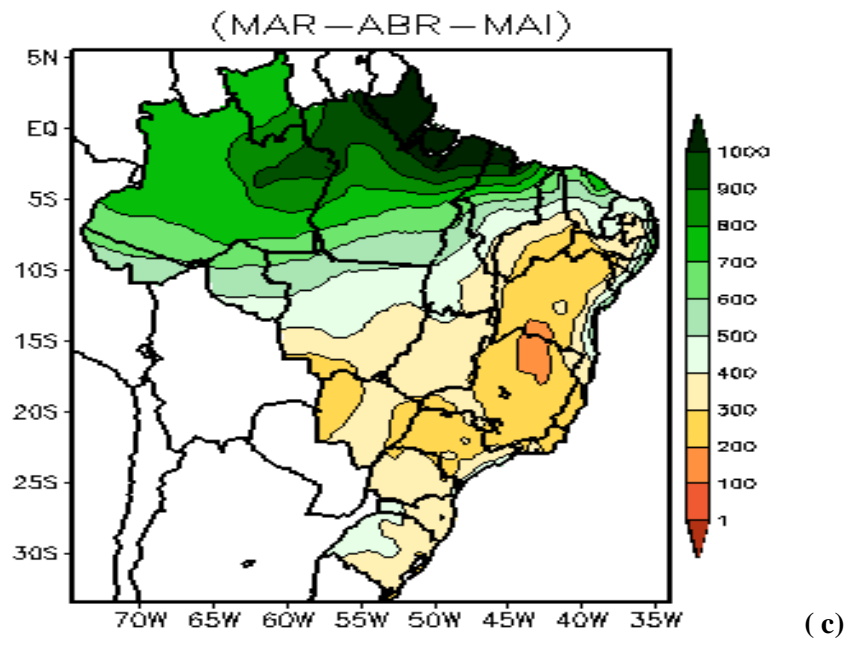


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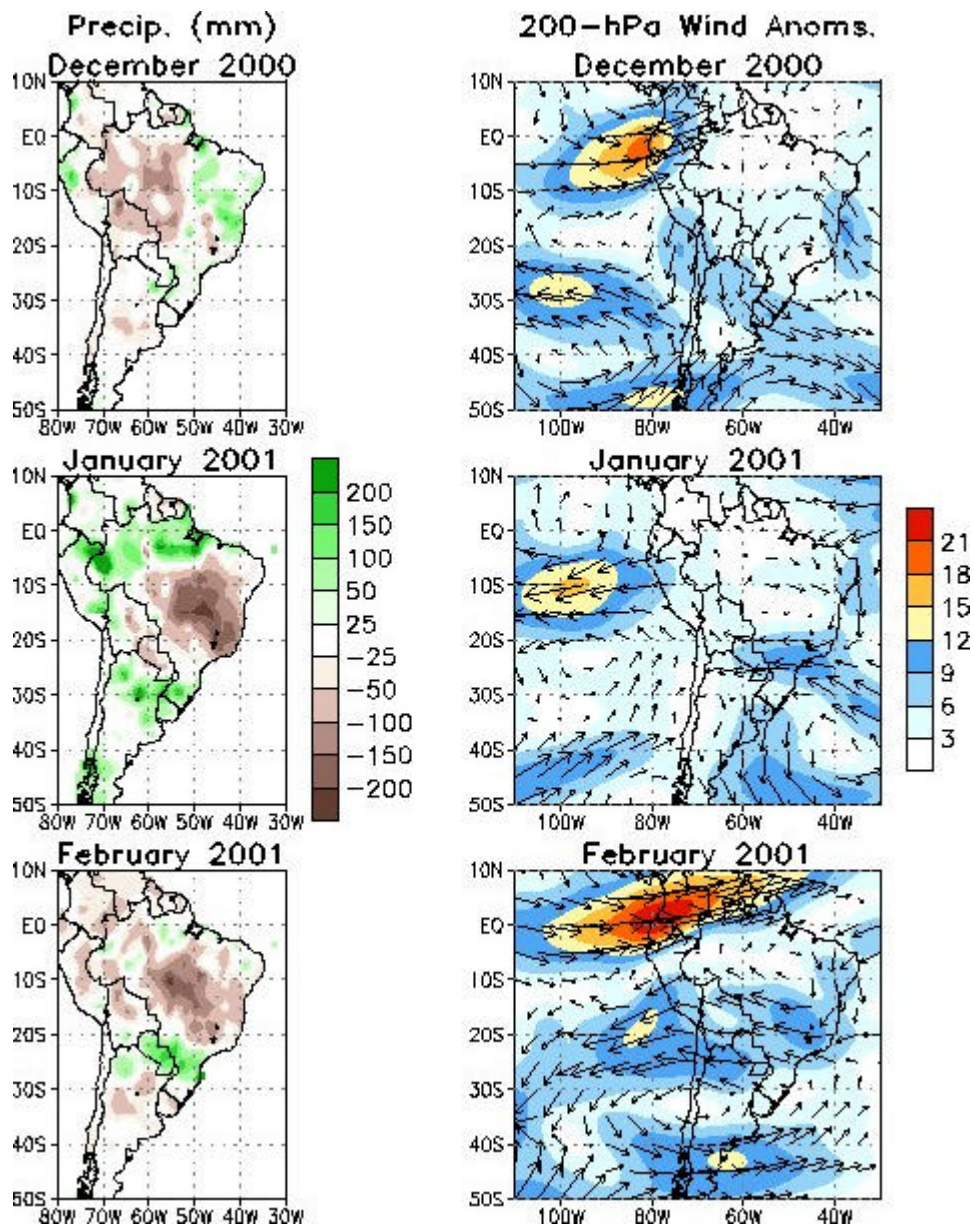


Fig. 2. Precipitation anomalies (mm) and 200-hPa wind anomalies ( $\text{m s}^{-1}$ ) for December 2000, January 2001 and February 2001.

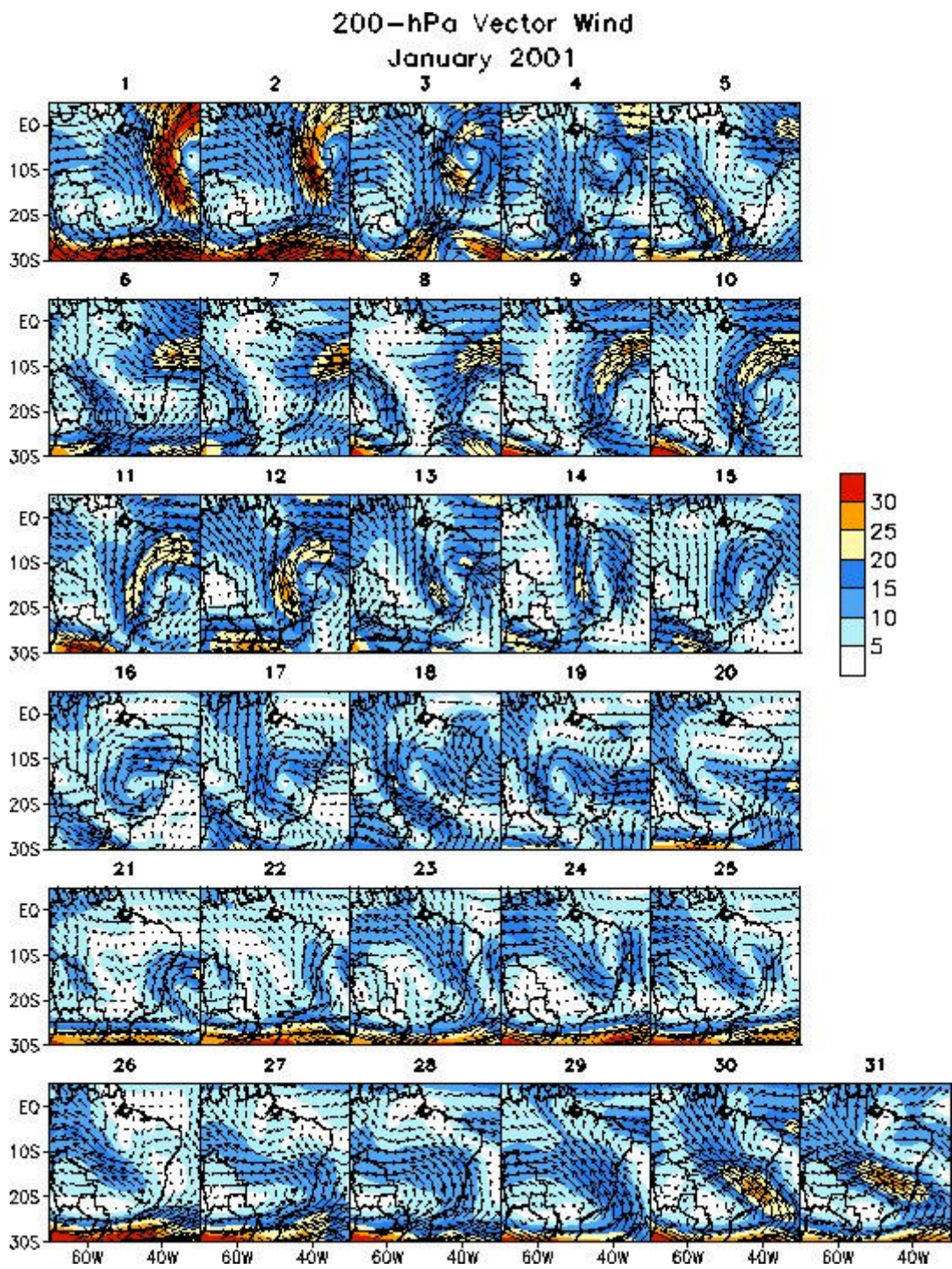


Fig. 3. Daily 200-hPa wind anomalies ( $\text{m s}^{-1}$ ) for January 2001.

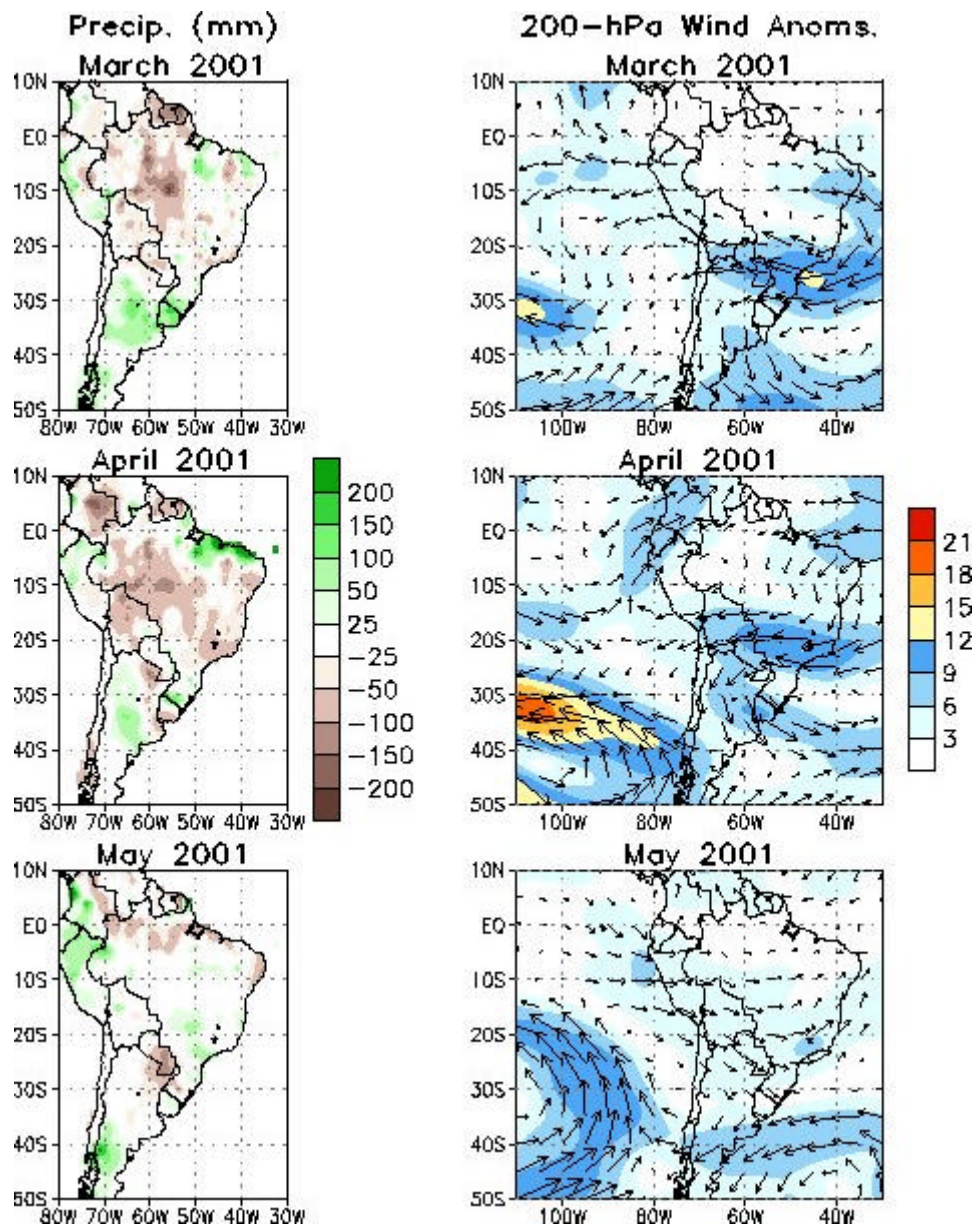


Fig. 4. Precipitation anomalies (mm) and 200-hPa wind anomalies ( $\text{m s}^{-1}$ ) for March, April and May 2001.

The daily precipitation for the region  $5^{\circ}\text{-}25^{\circ}\text{S}$ ,  $40^{\circ}\text{-}60^{\circ}\text{W}$  for the entire rainy season (September 2000 – April 2001) (Fig. 5) shows considerable day-to-day fluctuations in the intensity of precipitation. A Comparison of the observed rainfall to the long-term average (1979-1995) shows the persistent below-normal precipitation during January-April 2001. Also evident are alternating periods of above- and below-normal rainfall during the period September-December 2000, with maxima and minima occurring at intervals of approximately 45 days. This variability was related to rather vigorous Madden-Julian Oscillation (MJO) activity (Fig. 6), which at times has a strong influence on rainfall and



atmospheric circulation in many areas within the tropics and subtropics (e.g., Weickmann, 1983; Weickmann et al., 1985; Casarin e Kousky, 1986; Kousky e Kayano, 1994; Castro e Cavalcanti, 2001).

The MJO weakened during January-February, as La Niña conditions re-intensified in the tropical Pacific, and strengthened during March-April, as conditions in the tropical Pacific returned toward normal. During the latter period, MJO modulation of precipitation is again evident in the time series, while the mean precipitation for the period remained below normal.

The September 2000 – May 2001 mean anomalous precipitation (Fig. 7) shows a large area of central Brazil with rainfall deficits exceeding 400 mm. The main axis of the deficits extended from the southern Amazon southeastward to the planalto and portions of Minas Gerais, which is the normal axis of the SACZ. At the same time, southern Brazil, Uruguay, northern Argentina and the extreme north coastal areas of Brazil observed above-normal rainfall.

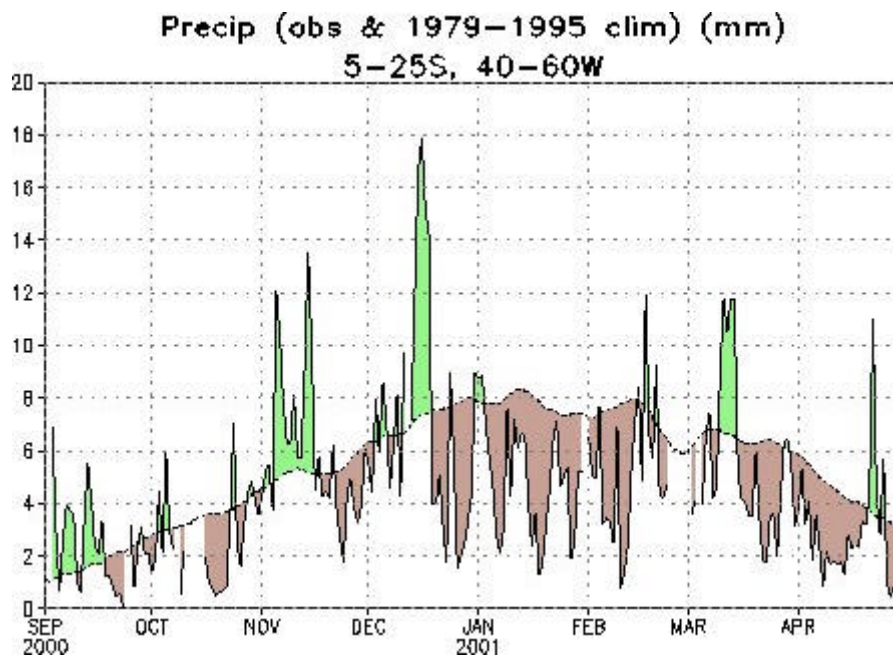


Fig. 5. Time series of daily precipitation (solid line) and the 1979-1995 daily-average precipitation (dashed line) for the region 5°S-25°S, 40°W-60°W, during September 2000 - April 2001.

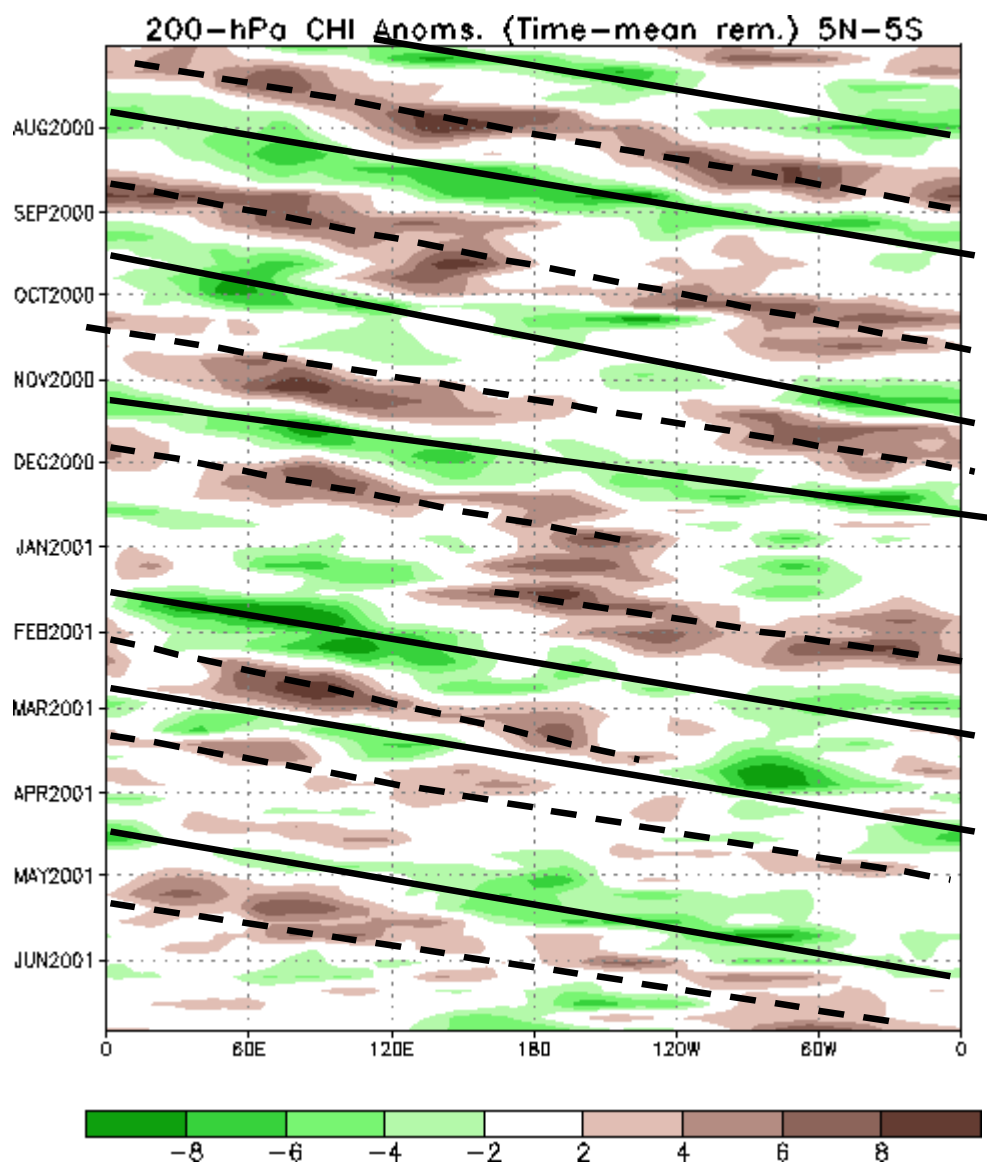


Fig. 6. Time-longitude section (5N-5S) of anomalous 200-hPa velocity potential. Solid (dashed) lines indicate the convectively active (inactive) phase of the Madden-Julian Oscillation. Strong MJO activity is evident during the last half of 2000.

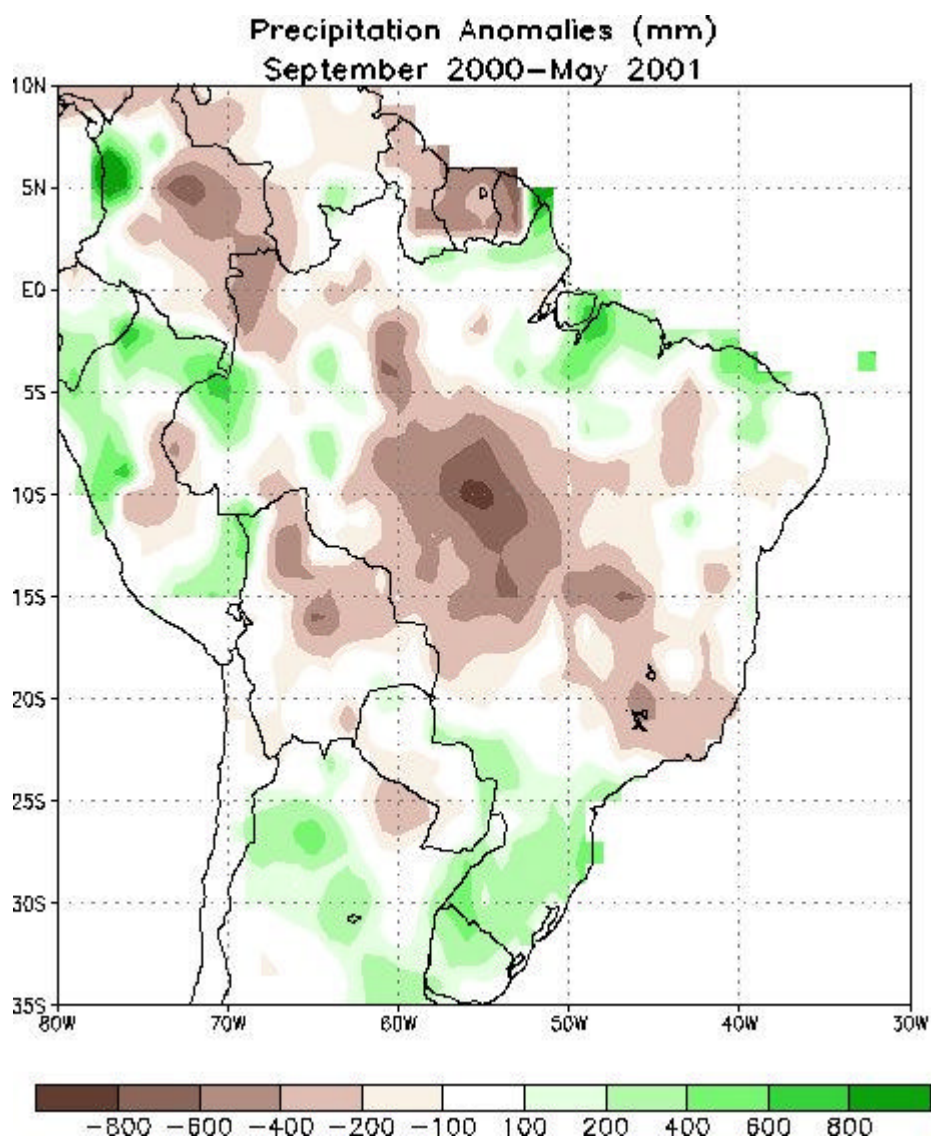


Fig. 7. Mean anomalous precipitation for September 2000 – May 2001.

### 3. Global situation

Strong negative anomalies of outgoing longwave radiation (OLR), indicating enhanced deep convection, dominated the region of Indonesia from mid-1998 through early 2001, associated with ongoing La Niña conditions in the tropical Pacific. In the past, La Niña conditions were generally accompanied by above-normal rainfall in the Northeast and below-normal rainfall in the South and Southeast, which is the opposite to the pattern observed during El Niño episodes (Cavalcanti et al. 2001). During the 1998-2001 La Niña period, the typical dipole pattern of precipitation anomalies was not observed over Brazil. Another interesting feature of the 1998-2001 La Niña is the marked annual cycle in many atmospheric and oceanic indices commonly used to monitor the state of ENSO. These show a moderate-to-strong cold episode (La Niña) conditions during the southern summer season

and weak or near normal conditions during the southern winter (e.g., see the Southern Oscillation Index time series shown in Fig. 8).

When La Niña conditions re-intensified during January-February 2001, enhanced convection intensified over Indonesia and positive 200-hPa height anomalies strengthened throughout the subtropics in both hemispheres (Fig. 9), as the subtropical jet streams shifted to higher latitudes. Significant height anomalies also appeared within the northern and southern mid-latitudes. In the Southern Hemisphere, a strong teleconnection pattern developed, linking the circulation features in the vicinity of Australia with features throughout the subtropical and extratropical South Pacific/ South American region. The observed pattern is quite similar to the Pacific South American (PSA) pattern described in previous studies of tropical/ extratropical interactions in the Southern Hemisphere (e.g., Mo and Higgins, 1998; Cavalcanti, 2000). The persistent nature of the observed anomalous circulation over South America during summer 2000/ 2001 and fall 2001 appears to be linked to the anomalous convection over Indonesia and a related downstream wave pattern extending from Australia to South America.

Other studies have demonstrated the link between mid-latitude wave trains over the eastern South Pacific and South America and the formation of VCANs near the Northeast coast (e.g., Kousky and Gan 1981); Chaves and Cavalcanti 2001). In a recent study (Chaves and Cavalcanti 2001) a wave train of vorticity anomalies was found to extend from the South Pacific to South America, with a cyclonic vorticity center over the Northeast during periods of drought in that region. The high number and deeper penetration into the continent of VCANs observed during January-February 2001 and the similarity of the overall height anomaly pattern to the PSA (Fig. 9) strongly suggests a link between the enhanced convection over Indonesia and the abnormally dry conditions that occurred over many sections of Brazil.

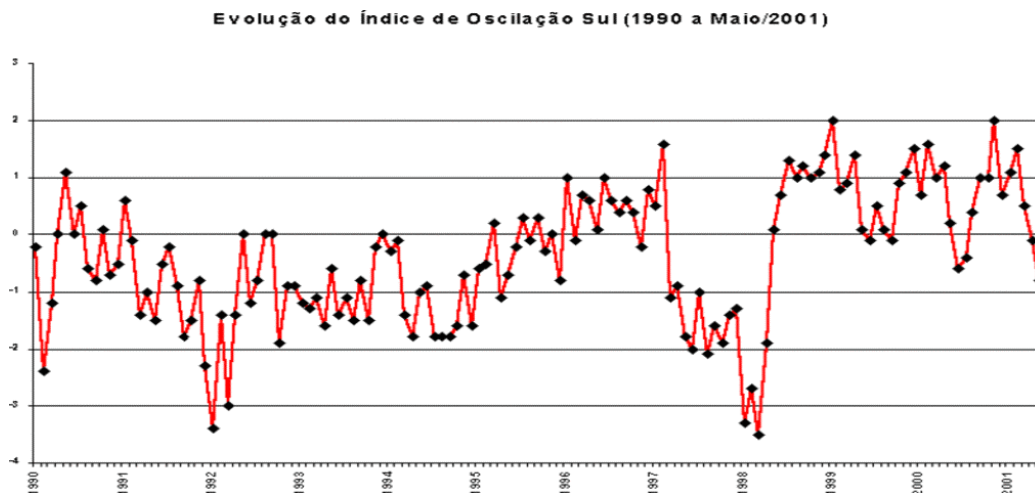


Fig. 8. Southern Oscillation Index for the period January 1990-May 2001.

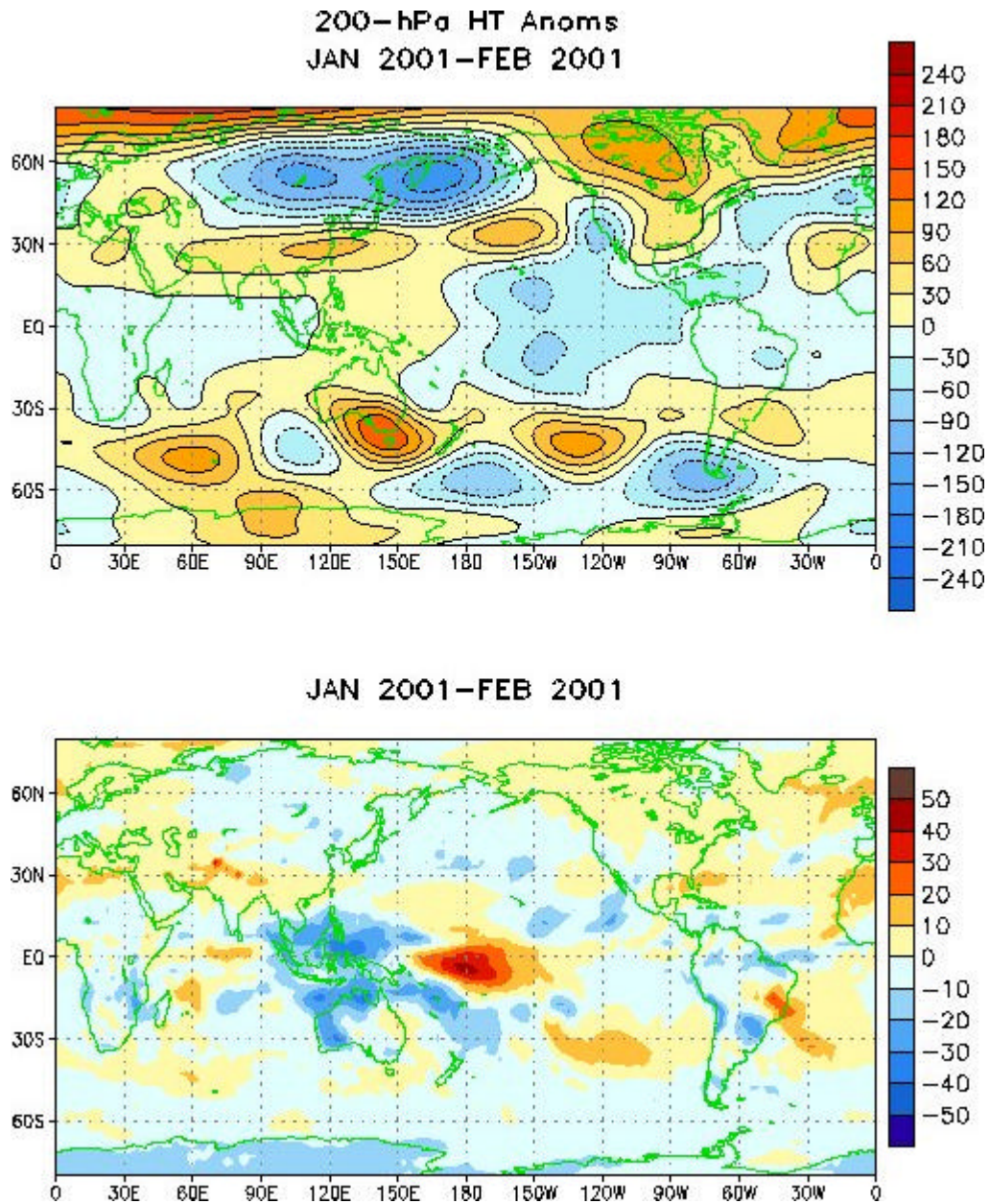


Fig. 9. Anomalous 200-hPa geopotential height and outgoing longwave radiation for January-February 2001.

#### 4. Conclusion

The summer 2000/ 2001 and fall 2001 drought over much of central Brazil (Central-West, Southeast and southern Northeast) was accompanied by: 1) greater than normal VCAN activity, with systems penetrating deep within the continent, 2) a PSA-like wave train of geopotential height anomaly centers extending from enhanced convection over

Indonesia/ northern Australia eastward to South America, and 3) stronger-than-normal subtropical ridges in both the Northern and Southern Hemispheres, associated with a re-intensification of La Niña conditions in the tropical Pacific. In addition, during both spring and fall the Madden-Julian Oscillation acted to strongly modulate rainfall on a time scale of about 45 days, which tended to accentuate the drier than normal periods within each season. By May 2001, the atmospheric circulation pattern over tropical and subtropical South America had returned to near normal, as the dry season set in over the drought-affected regions. During the southern winter, rainfall is generally light in these regions, and little relief from the drought could be expected prior to the onset of the subsequent rainy season, which on average occurs during September-October.

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