Rainy season duration estimated from OLR versus raingauge data and the 2001 drought in Southeast Brazil

by

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Abstract

The Southeast Region of Brazil is densely populated with high agricultural productivity, industrial activity and hydroelectric generation. Large precipitation deficits observed during the 2001 austral summer over this region contributed to the worsening of the energy crisis that was occurring in the country, with unprecedented social and economic consequences. Reliable information on the beginning of rainy season was essential for the Brazilian government to manage the energy crisis. The purpose of this study is to determine the rainy season in this region and to warn the risk of using OLR data to estimate the beginning of it. Pentad (5-day averaged) rainfall and OLR data showed that when OLR data is used, the beginning and the end dates of the rainy season are wrongly anticipated and delayed, respectively. This suggests that one should be careful in using OLR data to obtain information about the beginning and end of the rainy season. The present study aims to provide useful information for the management of the impact of adverse climate conditions such as the one in 2001, analysed with rainfall instead of OLR.

1. Introduction

The Southeast Region of Brazil (SEB) is the most populous and plays an important role in the economy of the country, being characterized by high industrial activity, agricultural productivity and hydro-energetic generation. Although Ramage (1971) did not consider South America as having a true monsoon regime, some studies revealed that a large part of subtropical South America experiences typical monsoonal circulation (Zhou and Lau, 1998: Gan et al., 2004). Particularly, SEB shows characteristics of a monsoon system, where the rainy season is the austral summer and the dry season is the austral winter. The three wettest and driest months correspond to DJF and JJA, respectively (Rao and Hada, 1990). Many studies (Kousky, 1988, Horel et al, 1989, Marengo et al., 2001a) have shown that the development of the monsoon system in South America starts during the spring season (SON). By mid-September deep convection develops over the northwestern Amazonia and advances rapidly southward reaching the Southeast Brazil by mid-October. The maximum rainfall intensity occurs in DJF when the deep convection is present over a large part of the tropical South America. Gan et al. (2005), analysing the interannual variability of the rainy season associated to the monsoon over South America for a 18-year period of precipitation time series (1979-80 to 1996-97), obtained that the earliest and latest onset dates occurred in 13-17 September and 12-16 November, respectively, and the mean onset and the standard deviation for the onset were 13-17 October and 15 days, respectively.

During the 2001 austral summer the total rainfall was much lower than the normal values in the southeastern, northeastern and Central Brazil. Large precipitation deficits observed over these regions contributed to the worsening of the energy crisis that was occurring in the country. The level of water in the dams located in SEB fell drastically. Fig. 1 illustrates the impact of the lower than normal values of precipitation at Rio Grande Basin on the natural discharge (discharge with no human interference) and net reservoir volume (volume of water available for consumptions) at Furnas, which is located in SEB. In order to try to control the crisis, the Brazilian government imposed a rationing in the consumption of power in the beginning of the dry season (June 2001), which continued until March 2002. This led to a reduction in Brazilian consumption of around 24%, affecting even other regions where there was no rationing (Bardelin, 2004). Most people in several regions of Brazil maintained the same the energy consumption so that it did not return to that observed in the period before the beginning of the energy rationing, even when it was finished. In particular in the case of SEB the energy consumption, which was higher than 15000 GWh before May 2001, became around 13000 GWh in June 2001 and remained lower than 12000 GWh up to December 2002. This energy crisis provoked significant social and economic consequences.

In order to help the Brazilian government to manage the energy crisis the Minister of Science and Technology created a working group at Center of Weather Prediction and Climate Studies (CPTEC) that was entrusted with the task of analysing the situation of the water level in the power plant reservoir and to predict the beginning of the rainy season. To this working group was given the responsibility of issuing bulletins in real time. Many efforts have been made to give accurate information on the beginning of rainy season, which was essential for the Brazilian government to manage the energy crisis. Several criteria may be used to estimate the beginning of the rainy season. Some studies use satellite-based outgoing longwave radiation (OLR) data to infer the precipitation. Although most of the studies that have been based on OLR anomalies are on the subject of intraseasonal variability of precipitation in South America (Nogues-Paegle and Mo, 1997; Nogues-Paegle et al., 2000; Carvalho et al., 2004; Gonzalez et al., 2006, and many others), there are a few investigations using OLR to identify and predict the onset of the rainy season in South America and they are mainly devoted to understand the onset in the Amazon basin (Kousky, 1988; Horel et al., 1989, Marengo et al., 2001a). Other criteria are based on rainfall data from raingauge station (Rao and Hada, 1990; Cavalcanti et al., 2001) and winds (Gan et al., 2004, 2005). In the particular case of the severe drought of 2001, Marengo et al. (2001b) using OLR data suggested that the rainy season over the basins responsible for the generation of electric energy in SEB begins between the end of September and beginning of October. Cavalcanti et al. (2001), using daily data of precipitation from Instituto Nacional de Meteorología (INMET) for the period 1979-1997, showed that there is large variability in the beginning of the rainy season in SEB. However, on the average it begins between in the end of October and beginning of November. The use of different methods leads to different results. The purpose of the present study is to determine the beginning of the rainy season in SEB based on rainfall data and to warn the risk of using OLR data to estimate it. This study aims to provide information for the management of the impact of adverse climate conditions such as the severe drought of 2001, which is a long range objective of CPTEC.

2. Data and methodology

Rainfall data of 189 raingauge stations for the period 1981-1996 were obtained from Agencia Nacional de Energia Eletrica (ANEEL) and Sistema Integrado de Gerenciamento de Recursos Hidricos do Estado de Sao Paulo (SIGRH). Fig. 2 shows the location of these stations. OLR data for the same period were obtained from NCEP/NCAR reanalysis (Kalnay et al., 1996). Pentad (5-day averaged) rainfall and OLR data were calculated.

In order to determine the rainy season using precipitation data for each raingauge station (i) for each pentad (j) for each year (k) the value of the accumulated precipitation at each 5 days [p(i,j,k)] was compared to [P_5(i)], which represents the 5 days accumulated precipitation if the annual rainfall was uniformly distributed during the whole year. Starting from 1 January , a ratio r (i,j,k) = p (i,j,k) / P_5 (i) was calculated, where P_5 (i) = P (i) / 73, and P (i) is the mean annual rainfall. As criterion for the beginning (end) of rainy season it was assumed that at least 50% of the values of r (i,j,k) are higher (lower) than 1 at 4 consecutive pentads.

To determine the rainy season using OLR data the method used by Kousky (1988) was adopted. The criterion for the beginning (end) of rainy season was: a) pentad with OLR mean value lower (higher) than 240 W m^{-2}, b) at least 10 of the 12 earlier pentads with mean values of OLR higher (lower) than 240 W m^{-2}, and c) at least 10 of the 12 subsequent pentads with mean values lower (higher) than 240 W m^{-2}.

The number of the pentads and the respective calendar days are the following: pentad 1 corresponds to 1-5 January, pentad 2 to 6-10 January, … , pentad 73 to 27-31 December.

3. Results

The prediction of the onset, intensity and withdrawal of the monsoon is a set of complex problems on which many researchers are working (see Sperber and Yasunari, 2006). While the prediction of the arrival of the monsoon is a long range goal, the present study has a more modest and reasonable goal of determining when the monsoon arrives, i.e, to now-cast rather than to forecast. So, we use two different methods to determine the onset of the monsoon and compare the results.

First, the results using precipitation data from ANEEL and SIGRH are presented. As seen in Fig. 3a, the SEB shows distinct rainy and dry seasons. Starting from the pentad 53 (18-22 September) the rainfall begins to increase. The change from the dry to the wet season occurs during the pentad 58 (13-17 September). According to the criterion described in section 2 the beginning of the rainy season occurs during the pentad 59 (18-22 October) and its end during the pentad 18 (27-31 March). The change from the wet to the dry season occurs around mid-autumn (pentad 19, 1-5 April). The period with higher number of meteorological stations with r ≥ 1 occurs from the beginning of December (pentad 68, 2-6 December) to the end of January (pentad 5, 21-25 January) (Fig. 3b). During the rainy season in all the pentads the percentage of meteorological stations with r ≥ 1 is higher than 50%.

The results showed above indicate that the onset date of the rainy season obtained using the method based on rainfall is in agreement with the mean onset date and the variability of the onset dates for the monsoon in South America obtained by Gan et al. (2005) using wind and precipitation data. However, the end of the rainy season occurs 3 pentads (15 days) earlier than the mean demise date given in that study.

Figure 4 shows the distribution of OLR for the beginning and end of the rainy season in SEB. By mid-September (pentad 52, 13-17 September) a deep convection band, which develops over Amazonia (Fig. 4a), advances southeastward, arriving SEB by the end of September and beginning of October (pentad 55, 28 September - 2 October) (Fig. 4b). By mid-October (pentad 59, 18-22 October) a large cloudiness band with OLR values of 240 W m^{-2} **is** found over the entire SEB (Fig. 4c). By mid-April (pentad 21, 11-15 April) the cloudiness band starts to move towards the equator and in the beginning of May (pentad 25, 1-5 May) the end of the rainy season in SEB occurs (Figs. 4d-f). These results are in general agreement with earlier studies using OLR data, such as Kousky (1988) and Marengo et al. (2001b), where the beginning of the rainy season occurred in the beginning of October and between the end of September and beginning of October, respectively.

The results presented above show that when OLR data is used the beginning (end) of the rainy season occurs 4 (7) pentads earlier (later) compared with the use of rainfall data. The lag is larger in the case of the end of rainy season. This may be due to the movement of deep convection towards the equator is slower than its progress southeastward (Kousky, 1988; Marengo et al., 2001a). The slower movement of deep convection equatorward is suggested to be due to the storage of soil moisture during the rainy season (Gan et al., 2004). Thus the results of the present study show that there is a substantial difference in the determination of the rainy season when OLR data are used compared to the one determined with rainfall data. This must be taken into account when an accurate determination of rainy season is crucial to establish strategies to deal with adverse climate changes such as that of the 2001 severe drought.

The discussion above considered the mean start and end of the rainy season when precipitation and OLR data are used. The same criteria (section 2) were applied to years of El Niño and La Niña events. During the period 1981-1996 eight El Niño and four La Niña episodes have occurred (http://www.nws.noaa.gov). The El Nino and La Nina episodes and the pentad numbers corresponding to the beginning and end of the rainy season are given in Table 1. During El Niño events the maximum delay of the beginning of the rainy season (pentad 69, 7-11 December) occurred in the 1991-92 and 1993-94 episodes, while in the 1982-83 episode the rainy season extends up to the end of April (pentad 23, 21-25 April). The shortest (17 pentads) and longest (40 pentads) rainy seasons occurred respectively in the 1991-92 and 1982-83 episodes. In the case of the La Nina events the earlier end of the rainy season occurred in the 1983-1984 episode (pentad 6, 26-30 January).

When the determination of the beginning, the end and duration of the rainy season using OLR data is compared with the values obtained using precipitation data large differences can be noted, as seen in Table 1. For example, in the longest rainy season observed during El Nino events, which occurred in 1982-1983, the 'OLR method' delays the end of the rainy season by 11 pentads. This wrongly overestimates by 13 pentads the duration of the rainy season. The beginning and the end of the shortest rainy season observed in the 1991-92 El Nino event were respectively anticipated and delayed by 16 pentads causing an erroneous increase of 32 pentads in the duration of the rainy season with the use of OLR data. During years of La Niña events, large differences between the two methods are also seen. In particular, in the 1983-1984 episode there was an erroneous delay of the end of the rainy season (pentad 29, 21-25 May) with OLR data compared with the case when precipitation data was used (pentad 6, 25-29 January). This caused an increase in the duration of the rainy season by 26 pentads.

Thus, the results of the present work showed that there is an overestimation of the rainy season using OLR data. The anticipation of the onset of rainy season using OLR data is in agreement with the results of other studies on the energy crisis in SEB (see Marengo et al., 2001b and Cavalcanti et al., 2001). We tested the same criterion based on rainfall described in Section 2 for the meteorological stations located in the region of the basins responsible for the generation of electric energy in SEB and obtained that the beginning of the rainy season in SEB occurs at the end of November. The definition we used to determine the onset of the rainy season is a rigorous criterion in which the rainfall amount was enough for raising the low levels water in the reservoirs during adverse climate conditions such as the drought of 2001. Another test of the method based on rainfall data was made considering all the available meteorological stations of Sao Paulo State (SP in Fig. 2). In this test it was assumed as criterion for the beginning of the rainy season that r(i,j,k) was higher than 1 for at least 3 consecutive pentads or by 2 pentads followed by 3 pentads among 4 consecutive pentads. This criterion allowed an earlier onset of the rainy season compared with that assumed in Section 2, i.e, r(ij,k) higher than 1 for 4 consecutive pentads. This new definition is sensitive to the necessities of many sectors of society, such as agriculture, human activities and even electric sector (in situations different from that in the severe drought of 2001, when a heavy precipitation in the rainy season was needed to raise the low levels of water in the reservoirs). Although there was a relaxation of the criterion, the onset of the rainy season occurred between the end of October and beginning of November. Thus, even varying the definition of the criterion, the onset of the rainy season occurred later compared to the case when OLR data were used.

The overestimation of the rainy season using OLR data may be attributed to fact that OLR is a measure of convection, not necessarily rainfall. The criterion described in section 2, values of OLR lower than 240 W m^{-2}, indicates the presence of deep clouds that only show the probability of precipitation. However, non-precipitating high clouds like cirrus also show OLR values lower than 240 W m^{-2}. Thus the method may lead to unreal estimations of the rainfall.

Although in the present study the validity of the raingauge network data for estimation of precipitation is taken as granted, the method based on pentad rainfall data, described in Section 2, contains some limitations. Since the method is based on a precipitation time series data, the estimation of the rainy season assumes that the rainfall behaviour is similar to that of the past. Despite this limitation, the onset date of the rainy season obtained using this method is in agreement with the mean onset date and the variability of the onset dates for the monsoon in South America (Gan et al., 2005). Another method to determine the onset of the rainy season, which uses climate models predictions, is based on winds. Since the skill of climatic models to predict the wind components is better than to predict precipitation, monsoon indices based on wind changes may be used to estimate the rainy season in the future. This method has been applied with some success to the West-Central Region of Brazil (Gan et al., 2004, 2005). However, there is a need of many other tests for the various regions of the country.

4. Conclusions

In this study the rainy season in SEB is determined and warned the risk of using OLR data for this purpose. In addition, the changes in the beginning and end of the rainy season change during El Nino/La Nina events using OLR data were also examined. The study aimed to provide information for the management of the impact of adverse climatic conditions such as the severe drought in 2001. Pentad rainfall data from 189 raingauge stations and OLR data from NCEP/NCAR reanalysis was used. The results showed that when precipitation data was used the beginning and the end of the rainy season in SEB occurred respectively during the pentad 59 (18-22 October) and pentad 18 (27-31 March). When OLR data were used the beginning and the end of the rainy season were wrongly anticipated (4 pentads earlier) and delayed (7 pentads later), respectively. When OLR data were used for the determination of the rainy season during El Nino and La Nina events large differences in relation to the precipitation data were also noted. In the case of El Nino episodes the beginning and the end of the rainy season were wrongly delayed and anticipated, respectively, up to 16 pentads while in the case of La Nina episodes the duration of the rainy season was erroneously increased up to 26 pentads.

Thus the wrong inference of the rainy season with OLR leads to the conclusion that these data should be used carefully mainly in the case of adverse climatic conditions such as the severe drought of 2001, when an accurate information on the beginning of the rainy season was essential for the Brazilian government to manage the energy crisis. Since the date of the onset of the rainy season obtained with precipitation data showed a good agreement with those obtained for the monsoon in South America, the criterion used here may be useful to determine the rainy season in SEB. Thus, the present study attempted to provide meaningful and reliable information for decision makers.

It should be noted that in regions where surface raingauge stations are not available the only precipitation data source is the satellite inferred (OLR and other means) one. However, in view of our results one should exercise greater care in inferring quantitative rainfall.

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Legend of figures

Fig. 1: a) Monthly mean precipitation (P) during 2001 and long-term mean (LTM) at Rio Grande Basin (mm). Source: meteorological stations from INMET and Data Collection Plataforms from INPE (http://www.cptec.inpe.br/energia/bacias/posto_riogrande.shtml); and b) Natural discharge (ND) and net reservoir volume (NRV) at Furnas. Source: Operador Nacional do Sistema Elétrico (ONS). The region of Rio Grande Basin (black line) and the location of the Reservoir of Furnas (red circle), which are located in SEB, are shown in the upper left side of b).

Fig. 2: Station location map. The schematic map of the entire country of Brazil including the location of the area of study is showed in the upper left side of the figure. The letters SP, MG, RJ and ES correspond respectively to the States of Sao Paulo, Minas Gerais, Rio de Janeiro and Espirito Santo.

Fig. 3: Values of r (i,j,k) at each pentad (a), and the percentage of meteorological stations with r (i,j,k) ≥ 1 at each pentad. The dates correspond to the center of the pentads.

Fig. 4: Distribution of OLR values for: a) pentad 52 (13-17 September), b) pentad 55 (28 September - 2 October) (beginning of the rainy season), c) pentad 59 (18-22 October), d) pentad 21 (11-15 April), e) pentad 25 (1-5 May) (end of the rainy season), and f) pentad 29 (21-25 May).

Table legend

Table 1: Beginning, ending and duration of rainy season during El Nino (EN) and La Nina (LA) events using precipitation (P) and OLR data. Also shown are the mean climatological data (Mean). * indicates the shortest rainy season and the earlier beginning or end of rainy season; ** corresponds to the longest rainy season and the maximum delay in the beginning or end of rainy season.

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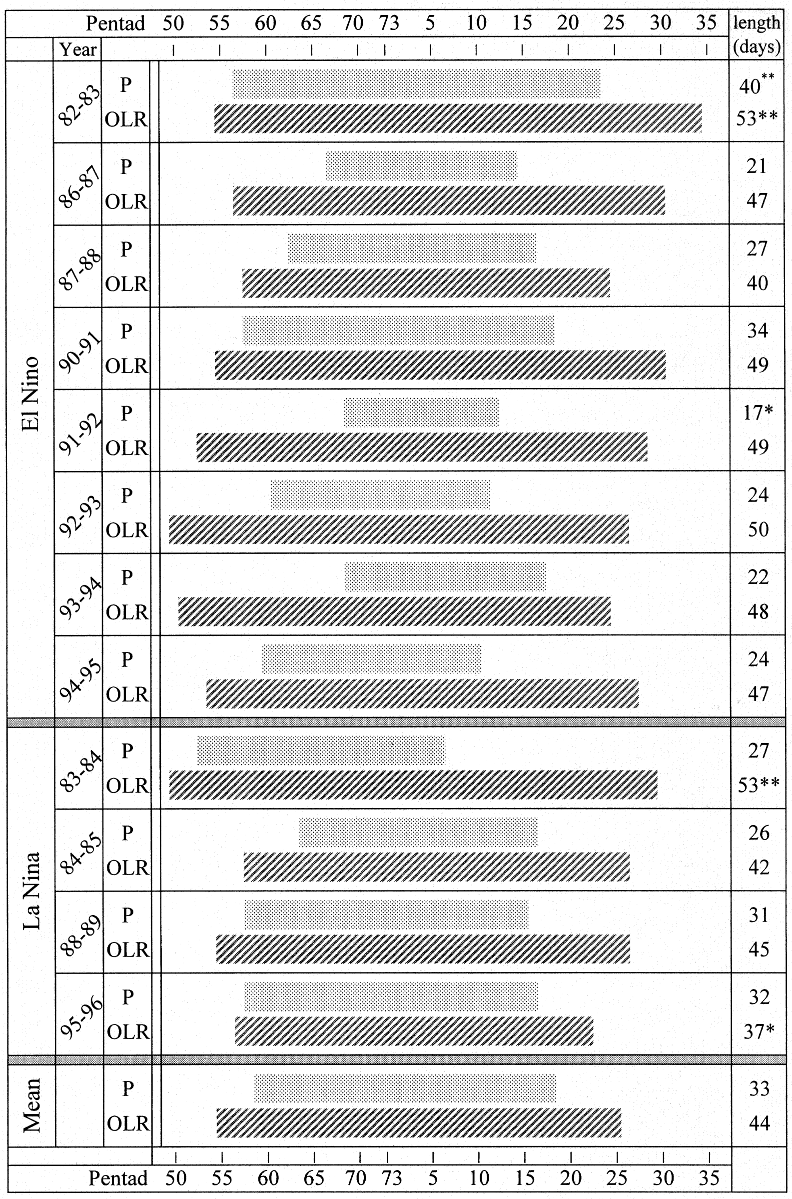

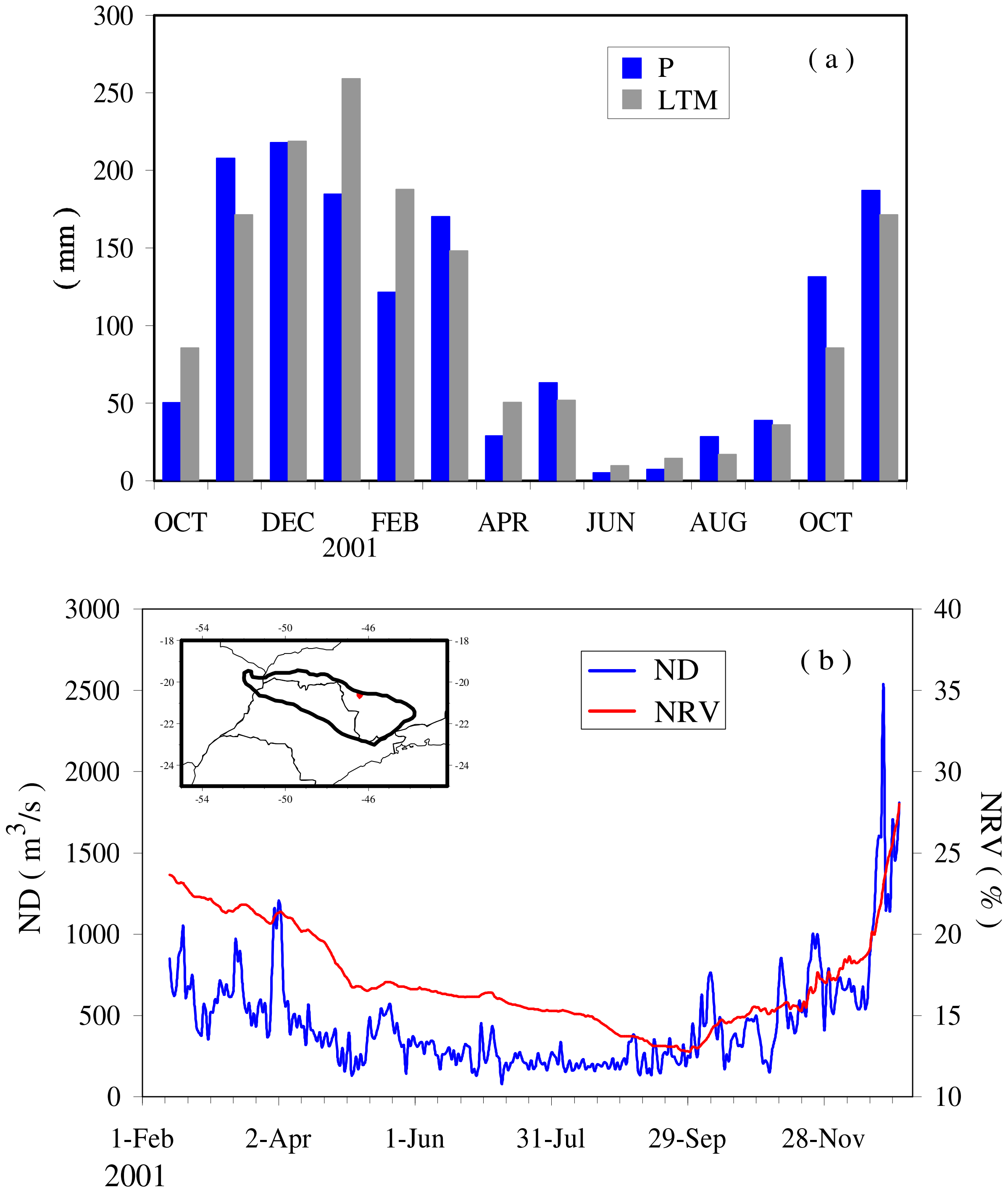

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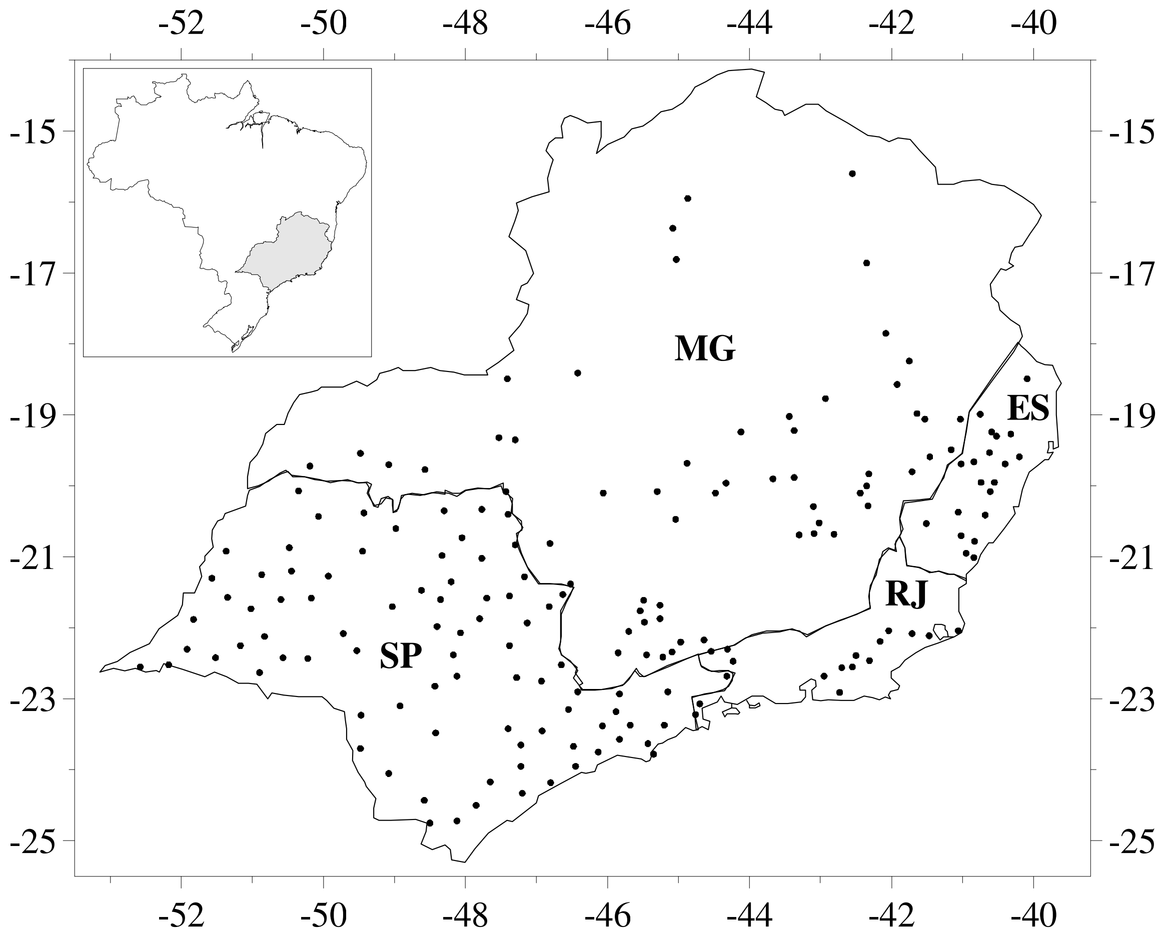

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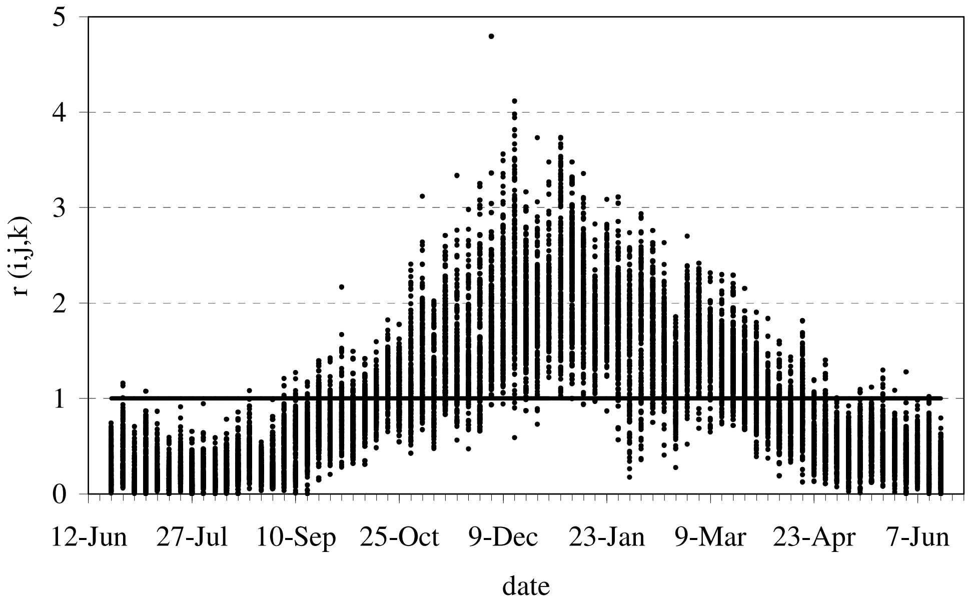

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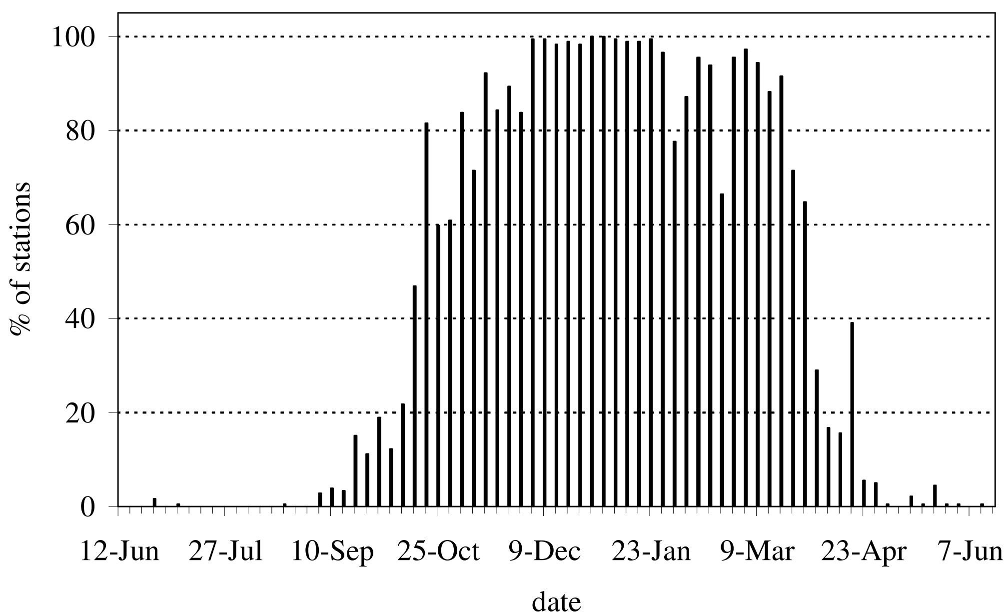

(b)

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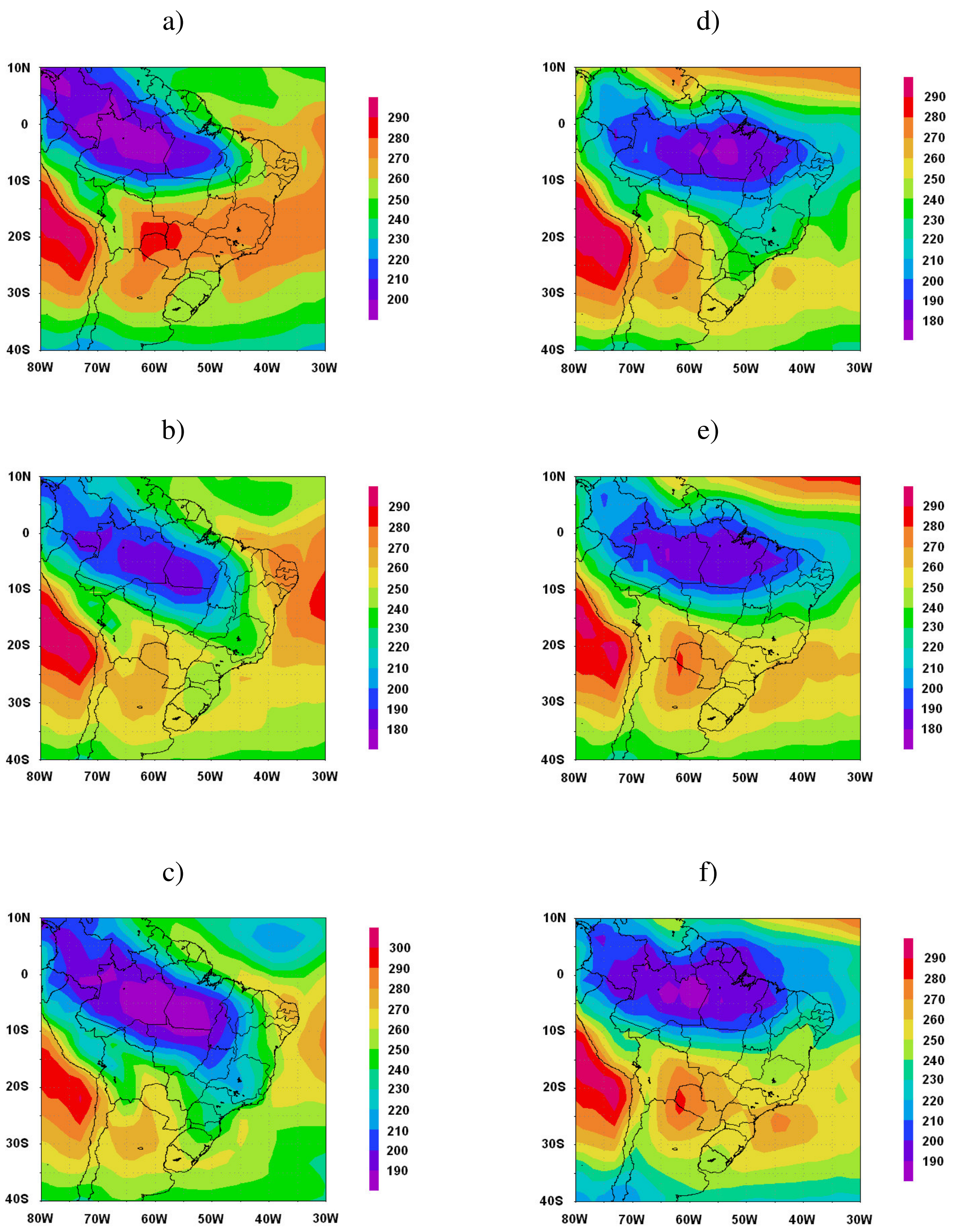

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