

# THE DROUGHT OF AMAZONIA IN 2005

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## RESUMO

Grandes extensões da Amazonia ocidental experimentaram uma das secas mais intensas durante os últimos 100 anos. A seca afetou a população que mora próximo do Rio Amazonas e seus tributários os Rios Solimões e Madeiras na parte ocidental da Amazonia. Navegação nestes rios teve que ser suspensa porque os níveis dos rios baixaram a extremos históricos. A seca não afetou a parte central e leste da Amazonia, o que é uma característica típica de secas associadas ao El Nina como foi em 1926, 1983 e 1998. A escolha do arquivo de chuva pode ter influenciado a detecção da seca. Em tanto que alguns arquivos de chuva (de estação ou em ponto de grade) mostraram anomalias negativas de chuva outros apresentaram chuva acima do normal na Amazonia do oeste.

As causas da seca não foram associadas ao El Nino, mais foi associadas a (a) Atlântico tropical do norte anormalmente mais quente, (b) enfraquecimento dos ventos aliseos e do transporte de umidade do Atlântico tropical para a Amazônia durante a estação chuvosa de verão, e (c) enfraquecimento do movimento vertical de Ascenso do ar nesta parte da Amazonia inibindo o desenvolvimento de convecção e chuva. As condições de seca foram intensificadas durante a estação seca ate Setembro 2005 quando a umidade do ar foi muito menor que o normal e as temperaturas do ar chegaram ate 3-5 °C acima do normal. Como consequência da intensa estação seca nesta região, incêndios florestais afetaram grande parte da Amazonia ocidental. Chuvas voltaram à normalidade em Outubro 2005, gerando enchentes depois de Fevereiro 2006.

## ABSTRACT

Large sections of southwestern Amazonia experienced one of the most intense drought episodes from the last 100 years. The drought severely affected the population downstream along the Amazon River main channel and its western and southwestern tributaries the Solimões (also known as Amazon River in the other Amazon countries) and the Madeira Rivers. Navigation along these rivers had to be suspended because the water levels fell to historic lows. The drought did not affect central or eastern Amazonia, different from the El Niño-related droughts in 1926, 1983 and 1998. The choice of rainfall data used influenced the detection of the drought. While most data sets (station or gridded data) showed negative departures from mean rainfall, one data set exhibited above the normal rainfall in western Amazonia. The causes of the drought were not related to El Niño but to (a) the anomalously warm tropical North Atlantic, (b) the reduced intensity in northeast trade wind moisture transport into southern Amazonia during the peak summertime season, and (c) the weakened upward motion over this section of Amazonia, resulting in reduced convective development and rainfall. The drought conditions were intensified during the dry season until September 2005 when humidity was lower than normal and air temperatures 3-5 °C warmer than normal. Due to the extended dry season in the region, forest fires affected part of southwestern Amazonia. Rains returned in October 2005 and generated flooding after February 2006.

**Key words:** Drought, Amazonia, climate change

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## INTRODUCTION

In 2005, large sections of the western Amazon Basin experienced the most severe drought in the past 40 years and also one of the most intense of the last 100 years. The international section of the 11 December 2005 issue of *The New York Times* reported that “*The drought has evaporated whole lagoons, and kindled forest fires, killed off fish and crops, stranded boats and the villagers who travel by them, brought disease and wreaked economic havoc*”. Navigation along sections of the Madeira and upper and central Amazon River (known in Brazil as the Solimões River), had to be suspended because the water levels fell to extremely low levels, which led various countries of the Amazon region to declare state of public calamity in September 2005. The drought left thousands of people short of food, caused problems to river transportation, agriculture, generation of hydroelectricity and also affected directly and indirectly the populations living along the Amazon River streams. Previous studies (See reviews in Marengo et al. 2006 and Ronchail et al. 2002) have identified negative rainfall anomalies in Amazonia associated with El Niño-Southern Oscillation (ENSO) events and to SST anomalies in the tropical Atlantic as well. The studies have linked some of major droughts in Amazonia to (a) the occurrence of intense El Niño events, (b) strong warming in the surface waters of tropical North Atlantic during the Northern Hemisphere summer-autumn season, or (c) both. Very intense El Niño events have been associated with the extreme droughts in 1925-26, 1982-83 and 1997-98 and the last two also experienced intense warming in the tropical North Atlantic along with warming in the equatorial Pacific. There is evidence of extensive droughts, and perhaps widespread fires, linked to paleo ENSO events occurred in the Amazon basin in 1,500, 1000, 700 and 400 BP, and these events might have been substantially more severe than the 1982-83 -and 1997-98 ones (Meggers 1994). The best documented case of an earlier drought event in Amazonia linked to El Niño event was during 1925-26 (Sternberg 1987, and Williams et al. 2005). Rainfall anomalies in the central-northern Brazilian Amazonia and southern Venezuela in 1926 were about 50% lower than normal.

Contrary to the above droughts, the droughts of 2005 as well as those in 1963-64 and in 1979-81 did not occur associated with El Niño events. While several studies analyze the droughts of 1982-83 (Marengo et al. 1998) and 1997-98 (Nepstad et al. 1999) and their impacts in climate, hydrology and fires in Amazonia, there are only casual references to the drought event of 1963-64. The variability of SST anomalies in the tropical Pacific is responsible for less than 40% of rainfall variability in the Amazon basin (Uvo et al. 1998), suggesting that the effect of other sources of variability, such as the meridional SST gradient in the inter-tropical Atlantic (that affects mostly northern and central Amazonia), or land surface processes and large frequency of transients from the South Atlantic (important for southern Amazonia) may be also important in the inter-annual rainfall variability in the region..

## **OBJECTIVES**

The main objectives of this study are to explore the main observed climatic and hydrological characteristics of the Amazonian drought of 2005, and can be summarized as: (a) assessment of basin-wide meteorological and hydrological characteristics during 2005 using river data as well as various rainfall data sets; (a) assessment of the upper and lower-level large and regional scale circulation fields since 2004 and detection of anomalies during 2005 that could lead to the drought; (c) An assessment of impacts of tropical Pacific and Atlantic SST variability during the drought in Amazonia in 2005, and comparisons with other drought years.

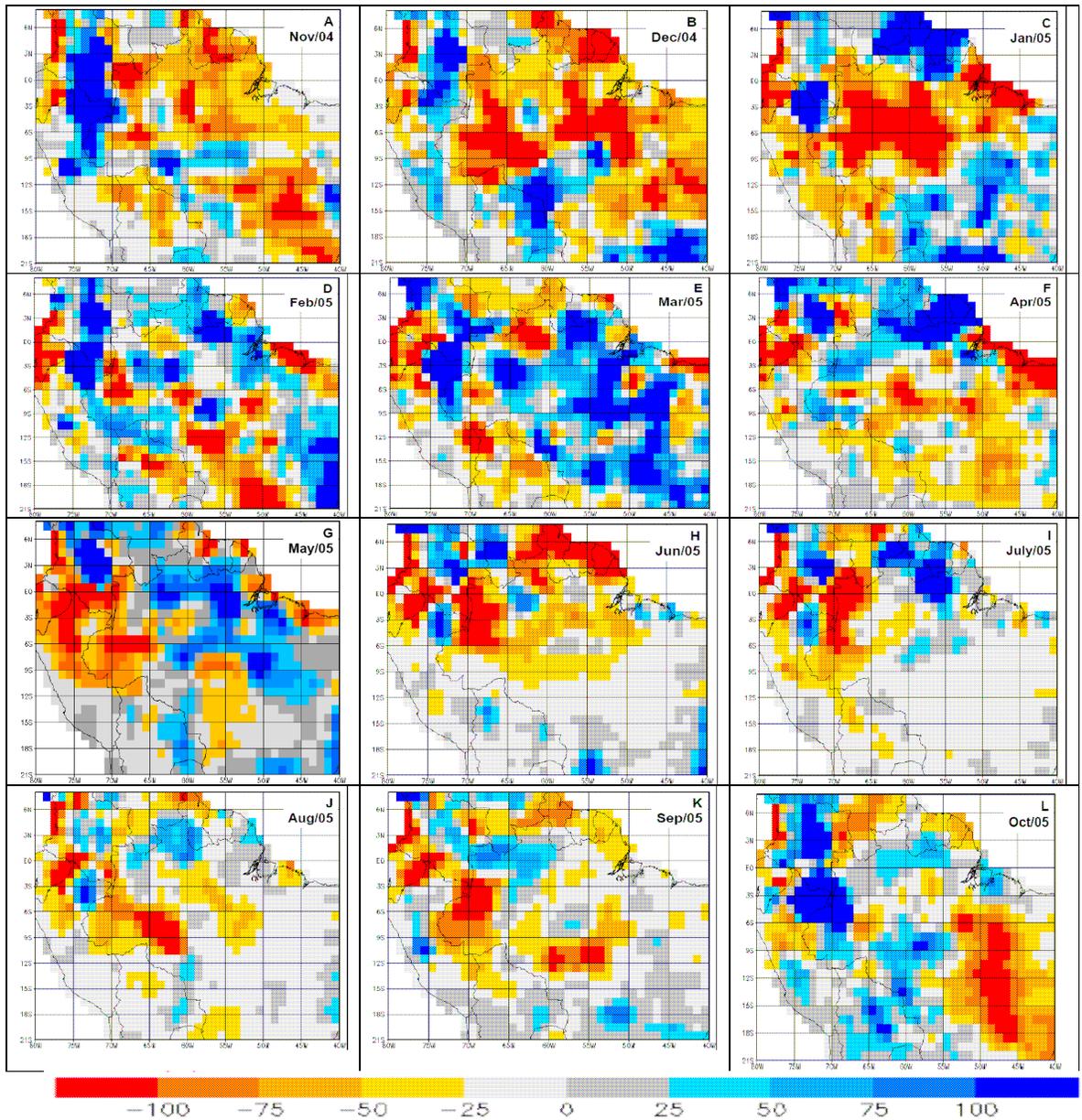
## **RESULTS**

### ***- The rainfall and hydrology characteristics of the Amazon basin during the drought of 2005***

The river levels in the Amazon region normally follow the seasonal cycle of precipitation. Rainfall in 2004 and especially in DJF and MAM of 2005 was below the long-term average for the western Amazon region, which caused rivers to drop to record low levels. Before analyzing the hydroclimatic characteristics of the drought of 2005, it should be pointed out that the Amazon Basin exhibits a wide seasonal variation in rainfall. The south-western part of the Amazon, where the basins of the Solimões, Madeira, Tapajós, Mamoré, Ichile and Beni Rivers are located, experiences its peak rainy season in DJF while the peak of the rainy season in north-central Amazonia (where the basins of the Negro and Uatuma Rivers are located) occurs during MAM. There is a lag of 2-3 months between the peak of the rainy season and the peak in streamflow/levels.

The sequence of maps of Fig. 1 exhibit rainfall anomalies from the GPCC for tropical South America from November 2004 to October 2005, and anomalies are estimated based on the 1961-1990 climatology. The anomaly maps indicate that the rainfall deficiency situation aggravated after September and October 2004 (not shown), and then from November 2004 through January 2005. From May through September 2005 negative anomalies larger than 100 mm/month were observed over western Amazonia. Isolated rainfall episodes in the central and eastern Amazonia are depicted by the positive anomalies in those regions. Most of the central and southern-western Amazonia experienced rainfall deficiency during the peak season in DJF 2004-2005, when rainfall was about 50-60% of the normal in the Solimões and Madeira River Basins, and about 80-90% of normal in the Rio Negro Basin. In MAM 2005 rainfall in the Solimões and Madeira River Basins was about 50-60% of normal while in the Rio Negro Basin rainfall shows values between normal and above normal (100-110%). After April 2005, rainfall anomalies started to become largely negative in southern and western Amazonia encompassing parts of Bolivia, Brazil and Peru. It is clear that the drought of 2005 differed from previous recorded events, since it strongly affected the southwest portion of the Amazon Basin. Because of the sheer size and significant travel time of the

streamflow in the Amazon Basin, the lower river flows of the southwestern portion occurred when the water levels were already receding at Manaus station. Therefore, rainfall anomalies strongly affected the water level at Manaus late in the dry season, increasing the river level recession in October while the peak discharge remains unaffected



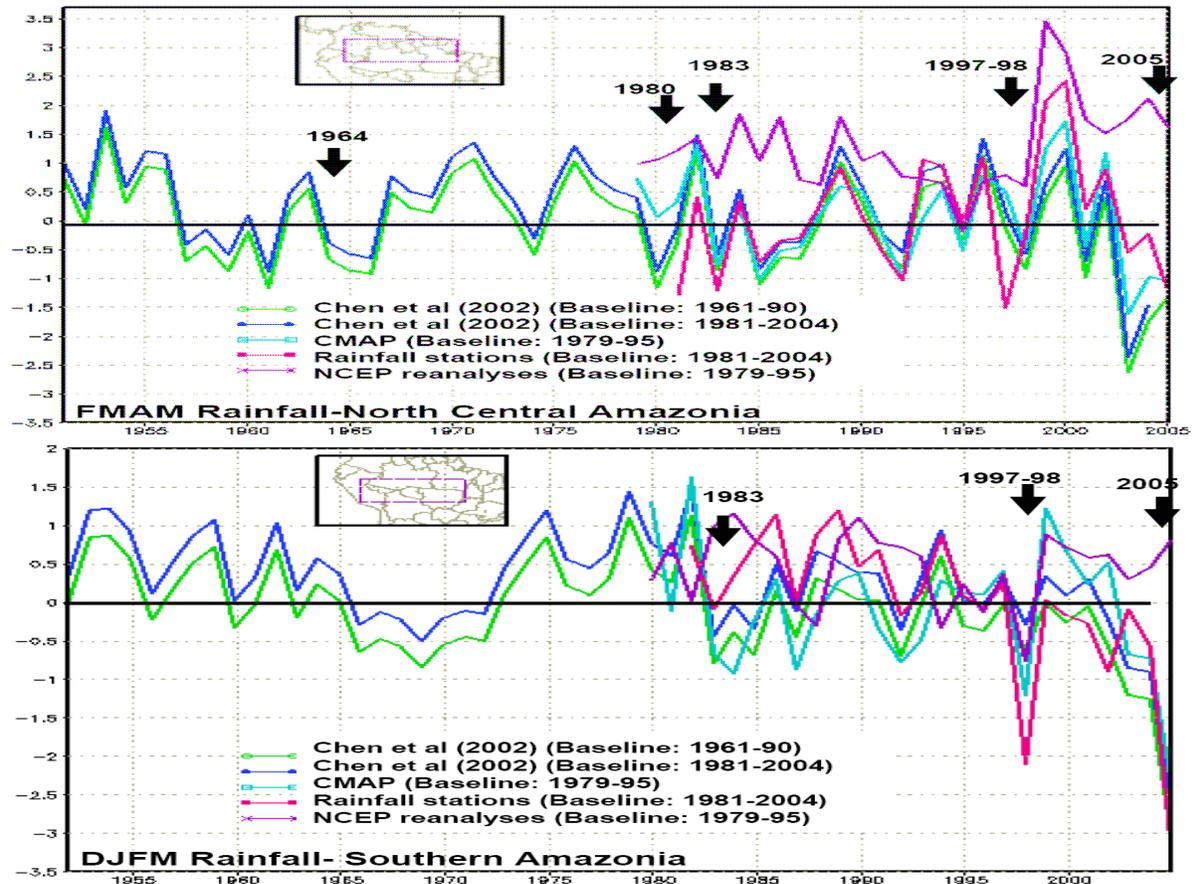
**Fig. 1.** Monthly rainfall anomaly maps for tropical South America from November 2004 to December 2005. Values as shown as deviations from the 1961-1990 long term mean. Data is from GPCP-Monitoring product available at 1.0° latitude/longitude gridbox area. Red/blue colors indicate negative/positive rainfall anomalies. Units are in mm/month.

*-The representation of the drought of Amazonia in 2005 by the different available rainfall data sets*

Rainfall time series during the peak rainy season in northern and southern Amazonia are shown in Fig. 2a-b for the peak season FMAM for northern and DJFM for southern Amazonia, respectively during 1950-2005. The figures show how various rainfall data sets can depict inter-annual variability and allows for an identification of reduced rainfall in the rainy season and possible droughts. The Chen et al. (2002) and CMAP gridded data sets were assessed for the period 1950 to 2005. In addition, indices of rainfall for northern and southern Amazonia were also calculated since 1980, and various reference periods were used to calculate anomalies from these indices (1961-90, 1981-2005, 1979-95 and 1981-2004). Regardless the systematic differences among all data sets, the rainfall series in northern Amazonia (Fig. 2a) show the large negative departures during the droughts of 1963-64, 1980-81, 1982-83, 1997-98 and 2005 in northern Amazonia. The index derived from rainfall stations shows the year 1998 with negatives anomalies of the order of 1.5 mm/day while 2005 exhibited 1 mm/day below normal, implying that the drought of 1998 was more intense than that of 2005. The rainfall index derived from the NCEP re-analysis is the only one that shows positive rainfall anomalies, in contrast with the other rainfall station and gridded data sets. In southern Amazonia, Fig. 2b shows that all rainfall indices characterize large negative departures in 1998 and 2005, with all data sets (except the NCEP data) showing between 2.5 and 3.0 mm/day below normal in 2005. In fact, the station rainfall data set shows the drought of 2005 was more intense in southern Amazonia, as compared to the previous drought of 1998 and 1983, being the El Niño impact in 1983 more intense in northern and central Amazonia. While the rainfall index derived from the NCEP re-analysis is consistent with the other indices for the El Niño events of 1987 and 1998, it differed from all the other data sets for 2005, showing a positive rainfall anomaly, both in northern and southern Amazonia. The NCEP rainfall index is the only one that actually ignores the drought in Amazonia and show positive rainfall anomalies between +0.5 and 1.0 m//day above normal. This is inconsistent with the tendencies from other data sets, and also with the situation observed in the level/discharges of rivers in southern Amazonia, possibly indicating systematic errors in the rainfall calculation of these reanalyses.

As consequence of rainfall anomalies, the levels of the Solimões River in Tabatinga and Fonte Boa were anomalously low during the El Niño events in 1982-83 and in a lesser degree in 1998, while the levels reached very low values during the drought of 2005. In Rio Branco, the lowest values on 2005 were part of a negative trend detected since the middle 1990's. Marengo et al. (2006) show the variability of levels/streamflow in central and eastern and southwestern Amazonia during 2004 and 2005, as compared to the LTM. From December 2004 to the end of the climatological peak water season in May 2005, the levels of the Amazon River in Iquitos, the Solimões River in Tabatinga and Fonte Boa, the Acre River in Rio Branco. The Negro River was 1-2 m above the normal from January to July 2005 in Manaus (Fig. 7b). Since August 2005 the river

levels dropped to values about 3 m below normal. It reached 18.61 m in September 2005 (September average=22.30 m). For comparison, the river level in Manaus reached 21.74 m in September 2004, and it dropped almost 4 m below-normal by September 2005. The large drops of river levels in Manaus were likely related to the low levels of the Solimões River upstream of the Manaus region. The water stage of the Negro River in Manaus is a combination of the signal produced by the Negro river itself and the nearby Solimões River. In fact, the influence of the drought on the Solimões River basin upstream of Manaus is partially responsible for the lower water levels of the Negro River in Manaus after June.

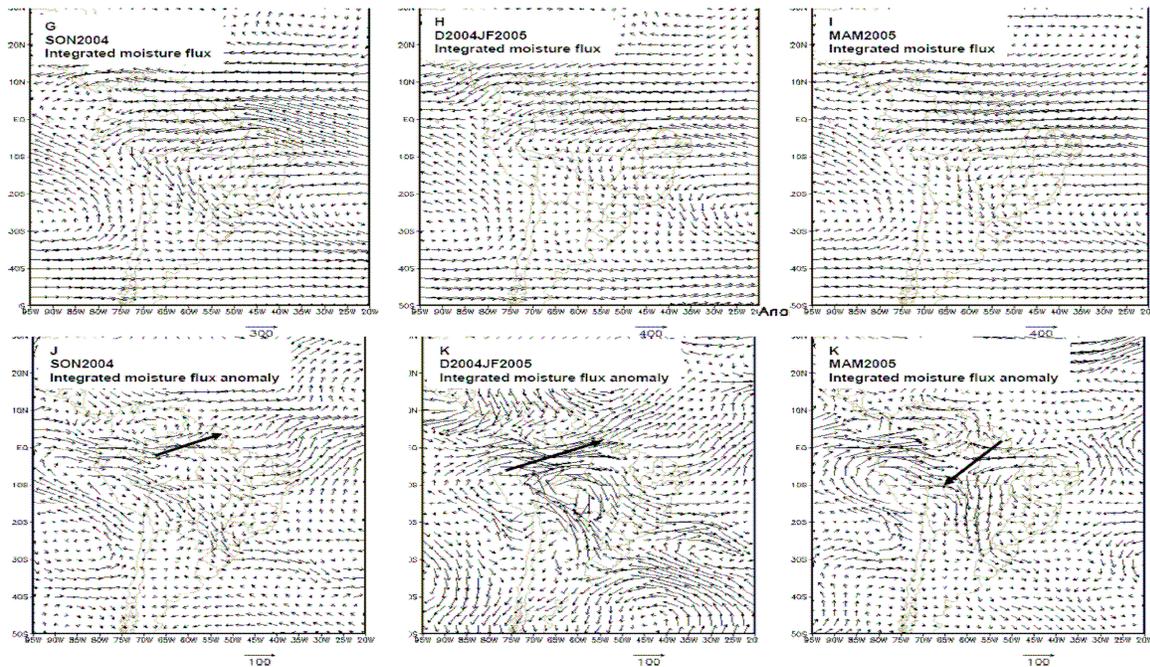


**Fig. 2a-b.** Time series of rainfall indices for northern Amazonia (FMAM, upper panel) and southern Amazonia (DJFM, lower panel) from 1950 to 2005. These seasons correspond to the peak of the rainy season in those sections of the Amazon Basin. Rainfall data come from different data sets. Anomalies (in mm/day) are derived using different baseline periods. Arrows indicate major drought events for this period (Marengo et al. 2006).

***-Basin wide characteristics of the upper and lower-level large scale and regional upper and lower-level circulation during the drought of 2005***

At the near-surface level, the wind maps and anomaly fields (Fig. 3) show that the moisture flux from the tropical North Atlantic into Amazonia was weaker than normal during the rainy season onset season in SN 2004 and during the peak of the rainy season (DJF 2004-2005) in southern Amazonia. The subtropical North Atlantic high weakened and was displaced northward

during this period. The northeast trades and moisture transport into the Amazon weakened, as shown by large moisture transport flux anomalies from the Amazon into the tropical North Atlantic. The presence of a cyclonic anomaly during the peak of the rainy season of 2005 over eastern Bolivia is associated with a strong southerly flow flux anomaly east of the Andes. This is also indicative of a reduction in the moisture flow from northern Amazon region to southwestern Amazonia. The southerly flow anomalies suggest a weakening of the Low Level Jet east of the Andes during DJF 2005 peak season, when this season normally shows the peak of LLJ activity. In fact, no events of LLJ were detected during December 2004-February 2005, while average number of jet events for this season is typically about 12. This pattern confirms that moisture transport from the tropical North Atlantic and northern Amazonia into southern Amazonia during the peak rainy season was extremely reduced. This altered pattern corroborates the different nature of this drought of 2005 as compared to other droughts.



**Fig. 3.** Low level circulation and integrated moisture flux in South America for SON 2004, DJF 2004-2005 and MAM 2005. Panels a-c and g-i represent the mean circulation and moisture transport, and panels d-f and j-l are the anomalies from the 1979-2005 mean. Vector with the scale of the wind/flux is shown on the lower side of each panel.

## CONCLUSIONS

The 2005 drought in the southwestern Amazon, possibly one of the most severe in at least 100 years, resulted from an extended dry season. Furthermore, the dry season in 2005 was more extreme than normal with drier and warmer conditions especially in southern and southwestern Amazonia. The effects of the drought were detected mainly in the levels of rivers whose drainage extend into southwestern Amazonia. There are some differences in the depiction of this drought in

Amazonia due to the use of different rainfall station data sets and compared to gridded analysis sources, as well as the consideration of the baseline to define the anomalies. While almost all data sets have shown, in less or greater extent drastic rainfall reductions in Amazonia during 2005, rainfall derived from the NCEP reanalysis exhibited positive anomalies of the order of up to +1.0 mm/day.

Comparative circulation and SST analyses for 2005 in relation to other years which there were El Niño-induced droughts (e.g 1926, 1983 and 1998, Marengo et al. 2006) have shown that the recent drought was concentrated in western and southern Amazonia, and not in north-central or eastern Amazonia (regions that typically experience rainfall deficiency and drought during El Niño years). In all of these drought years, the spread of forest fires in the region was noticeable even though in different regions for different droughts. The low level moisture transport from northern into southern Amazonia was severely affected during DJF 2005. During 2005 there were anomalously warm surface waters in the tropical North Atlantic, a tendency that has been detected since 2003, while surface waters in the equatorial Pacific were near normal, suggesting a drought induced likely by the warming in the tropical Atlantic. This seems to be the case also for the drought in 1963-64. In 2005 the contrast between the tropical North and South Atlantic SSTs was about 1.2 °C, surpassed only by the 1.8 °C in 1958. Furthermore, the long-term positive SST trends in the tropical Pacific and Atlantic Oceans featured a warming of about 0.5 °C between 1920 and 2005, and it is here suggested that a small SST increase on the mean SST field during the relatively colder decade of 1950-60 may have had smaller impacts as compared to similar or even smaller SST increase in the relatively warmer 1990-2000 decade.

### **Acknowledgements**

We thank funding from the Brazilian Research Council CNPq, the PROBIO project (PROJETO DE CONSERVAÇÃO E UTILIZAÇÃO SUSTENTÁVEL DA DIVERSIDADE BIOLÓGICA BRASILEIRA) from the MMA/BIRD/GEF/CNPq, the project *Using Regional Climate Change Scenarios for Studies on Vulnerability and Adaptation in Brazil and South America* funded by the Global Opportunity Fund-GOF from the United Kingdom Foreign Commonwealth Office, the GEOMA project and the CLARIS-EU project.

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