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ANALYSIS OF ATMOSPHERIC VARIABILITY OVER NORTHEAST BRAZIL DURING THE AUSTRAL SUMMER 2003-2004

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1. INTRODUCTION

Observational studies indicate that there are three distinct precipitation regimes in northeast Brazil (NeB), which are related to different meteorological features (e.g., Strang 1972; Kousky 1979; Rao et al. 1993). The first regime occurs over southern NeB during November-January, associated with frontal systems and the South Atlantic Convergence Zone (SACZ) (e.g., Kousky 1979; Silva and Kousky 2001). The second regime occurs over northern NeB during February-April, which is linked to the Intertropical Convergence Zone (ITCZ). The third regime occurs along the east coast of NeB during May-July, which has been related to the thermal contrast between the sea and the continent (Kousky 1981). Superimposed on the mean climate, NeB experiences intraseasonal, interannual and decadal variability due to regional and remote climate forcing, related to the El Nino/ Southern Oscillation (ENSO), Atlantic sea surface temperatures (SST), Madden-Julian Oscillation (MJO) and teleconnection patterns such as the Pattern North America (PNA) pattern and North Atlantic Oscillation (NAO) (Horel and Wallace 1981; Moura and Shukla 1981; Weickmann et al. 1985; Madden and Julian 1994; Kousky and Kayano 1994; Nobre and Shukla 1996).

During the austral summer of 2003-2004 excessive precipitation was observed in NeB that surpassed historical values and had serious consequences for society. Due to urban growth and population increase, excessive rainfall in large cities can accentuate social problems, such as public health, habitation and survival. In this regard, accurate forecasts of weather and climate conditions are increasingly important, in order to allow decision makers to take precautionary measures to protect the well-being of the general public.

This study investigates the meteorological conditions that contributed to the excessive rainfall that occurred over NeB during the austral summer of 2003-2004, with emphasis on the time scales associated with various meteorological phenomena. The method of analysis is the Morlet Wavelet Transform (Weng and Lau 1994, 1996; Vitorino et al. 2005).

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2. DATA AND METHODOLOGY

Data used in this study include monthly and daily outgoing longwave radiation (OLR), 850-hPa and 250-hPa wind, sea level pressure (SLP), sea surface temperature (SST), and indices of the PNA (Pacific North American) pattern and the Antarctic Oscillation (AAO) obtained from NOAA (NCEP/ Center Prediction Climate). The means and anomalies of these variables were computed for use in the analysis of the monthly and daily atmospheric variability over NeB during December 2003-January 2004.

An analysis of the monthly averages was made for December 2003-February 2004 with the intention of documenting the seasonal behavior of the atmospheric and oceanic variability in the Tropics. After that an analysis was made of the meteorological events that occurred in January 2004. To analyze the time scales of atmospheric variability we applied the Morlet Wavelet Transform (WT) technique locally and spatially (Daubechies 1992; Foufoula and Kumar 1994; Weng and Lau 1994; Vitorino 2003). To compute the local WT we used area-averaged time series for NeB (0º-10ºS, 40º - 70ºW) and indices of the PNA and AAO. In the case of the spatial WT we applied the technique at each grid point, selecting only the time scales that were obtained from the local analysis. The real part of the wavelet coefficients were analyzed for time scales of 2 to 100 days (synoptic and intraseasonal time scales) to determine the phase of the favorable/ unfavorable conditions that contributed to the development/ inhibition of convection.

3. RESULTS

3.1 Global Atmospheric Analysis

During DJF 2003-2004 positive SST anomalies were observed over the equatorial Pacific west of the date line, while SST anomalies were near zero throughout the equatorial eastern Pacific. The equatorial Pacific, as a whole, was in an ENSO-neutral state. Previous observational studies have shown that NeB can experience extreme wet (e.g., 2002) and extreme dry (e.g., 1980) conditions during ENSO-neutral years (Xavier et al. 2003; Xavier 2005; Climanalise 2004). This suggests that precipitation over NeB does not depend solely on conditions in the equatorial Pacific, and that other atmospheric mechanisms are important during ENSO-neutral years.

Figure 1 shows negative OLR anomalies over NeB, the equatorial central Pacific, the South Pacific Convergence Zone (SPCZ), equatorial Africa and the west coast of Mexico. The pattern suggests a propagation of anomalies from the Pacific to the tropical Atlantic via North America and via the subtropical South Pacific. Previous studies have shown a connection between the PNA and ENSO (Horel and Wallace, 1981; Nobre and Shukla, 1996). There have also been studies linking convective activity along the SPCZ with precipitation over eastern Brazil (e.g., Cassarin and Kousky, 1986).

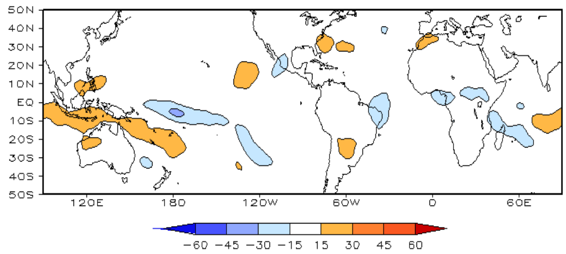
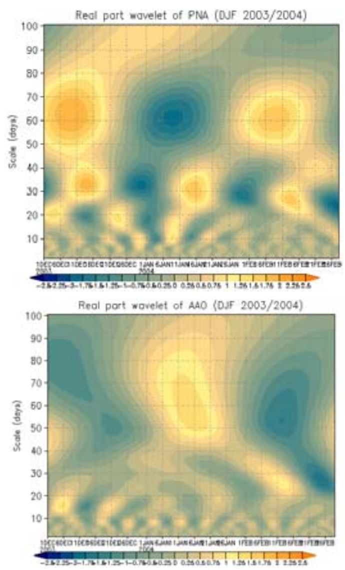


Figure 1. OLR anomalies for January 2004.

Figure 2 shows that, during December 2003-February 2004, the oscillations of the (a) PNA and (b) AAO are more accentuated at time scales (s) of around 30 and 60 days. This suggests that in the absence of ENSO forcing the PNA and AAO are strongly modulated by intraseasonal (MJO) variability. During January 2004 the AAO (Figs. 2b) was predominantly in its positive phase, which was associated with a reduction in the total number (3 events) of frontal systems that reached Southeast Brazil during the month (Climanalise, 2004).



(a)

(b)

Figure 2. Real part of wavelet of the PNA (a) and the AAO (b) for the period of December-February of 2003-2004.

North of the equator in the tropical Atlantic positive SST anomalies were observed during the season, while a band of positive anomalies extending from Africa to NeB developed along the equator in January. Negative SLP anomalies of up to -6 hPa were observed in the vicinity of the North Atlantic high-pressure system, which is consistent with weaker-than-average easterly winds and positive SST anomalies in the tropical North Atlantic.

Figures 3 and 4 show the monthly averaged evolution during DJF 2003-2004 of the phase of SLP and OLR fluctuations for time scales of 60 and 30 days. The circulation patterns in the Tropics show evidence of coherent intraseasonal oscillations, with a period between 30 and 60 days. In general, the OLR and the SLP are in phase over NeB, with positive (negative) anomalies in December (January). A dipole pattern is evident over Brazil that is consistent with above-average rainfall over practically all of Brazil, except the South. The positive phase over Indonesia is associated with below-average rainfall in that region. February was marked by the positive phase over NeB, the Pacific and the equatorial Atlantic (Figs. 3 and 4).

Figure 5 shows the reversal of the SLP anomalies over the tropical Atlantic/NeB (b) between December and the beginning of January. The OLR oscillation with a time scale of 45 days (Fig.5a), observed over the SPCZ (Fig. 3) displays a connection with NeB from the second week of December until the second week of January. These results suggest that the intraseasonal oscillations of 60 and 30 days reached NeB by two distinct trajectories during January; through the PNA teleconnection pattern during the first week of January and via the SPCZ (zonal) during the second week.

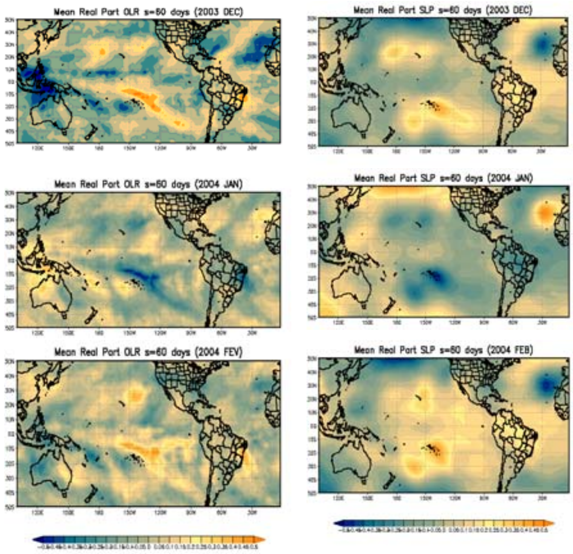


Figure 3: Average of the real part of the OLR (left hand panels) and SLP (right hand panels) for the time scale s = 60 days for December 2003 (top), January 2004 (middle) and February 2004 (bottom).

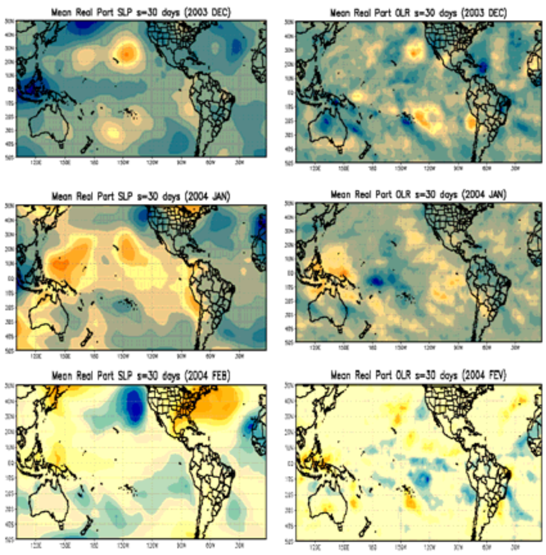
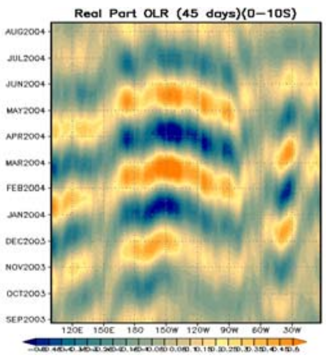
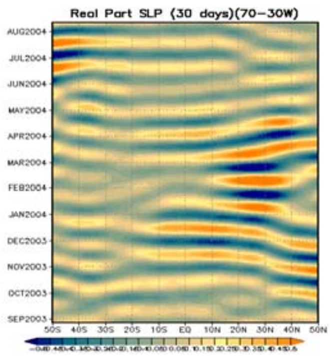


Figure 4. Same for Figure 3, except for the scale s = 30 days



(a)



(b)

Figure 5. Time-longitude (average for 0-10S) section of the real part of wavelet of OLR of s = 45 days (a) and time-latitude (average for 70-30ºW) for SLP of s=30 days (b).

3.2 Regional Atmospheric Analysis - Case Study

Figure 6 shows the precipitation observed over NeB during the September 2003-May 2004 rainy season. The extreme rainfall event of January-February 2004 is readily apparent. The analyses of the intraseasonal time scales in the previous section indicated the role of global-scale mechanisms in modulating the meteorological conditions that affected rainfall during January. However, regional scale atmospheric phenomena also played a role in producing the extreme rainfall event.

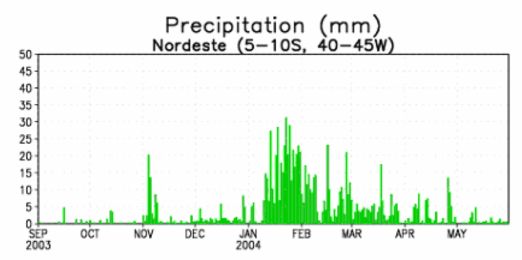


Figure 6. Spatial average of precipitation for NeB during summer 2003-2004.

In general, during the month of January of 2004 diverse meteorological systems were observed over NeB, such as upper-level cyclonic vortices (ULCV), the ITCZ, frontal systems (FS) and the South Atlantic Convergence Zone (SACZ). The ULCV affected the region during 1-3 January, 20-21 January, 28 January and 30-31 January. The ITCZ shifted south of its climatological position during the middle of the month, influencing the northwest portion of NeB (Pará, Maranhão and Piauí). During the last half of the month the ITCZ continued to strongly affect the northwest portion of NeB (Climanálise, 2004).

Of the three FS that affected Brazil in January two of them contributed to intensification of convection over NeB. FS (intense SACZ) influenced NeB during 3-6 January, with the SACZ located over southern Bahia, and during 11-20 January when the SACZ was located between southeastern Brazil and Bahia.

Figure 7 shows time series of OLR, U850 and V850 and their respective scalograms of phase averaged over NeB (5º-15ºS, 40º-50ºW). These indicate that during January time scales of 70 and 20 days for OLR, 40 and 20 days for U850, 50 and 20 days for V850 dominated the variability over NeB. A case study will be represented for the period of sudden transition in the OLR signal (negative anomalies) and U850 (westerly anomalies) during the middle of January (11-20). This in accordance with the period of influence of the intraseasonal oscillations of OLR from the SPCZ that culminated in the associated strong rain episode to the SACZ over the coast of the Bahia, the ITCZ near the north coast, enhanced convection in the Amazon and a VCAN along the coast of the Bahia during the latter part of the period.

In Figure 8 considerable space variation of the phases of wavelets of OLR and SLP is evident over NeB during the period of 10-20 January. One notices that the scale of 45 days, with negative phase (favorable the convective activity), covered an extensive area of the Atlantic and NeB. The pattern for the 20-day time scale, which is consistent with enhanced convection over the southern NeB, reflects the intense FS and SACZ that was present over that region during the last half of the month.

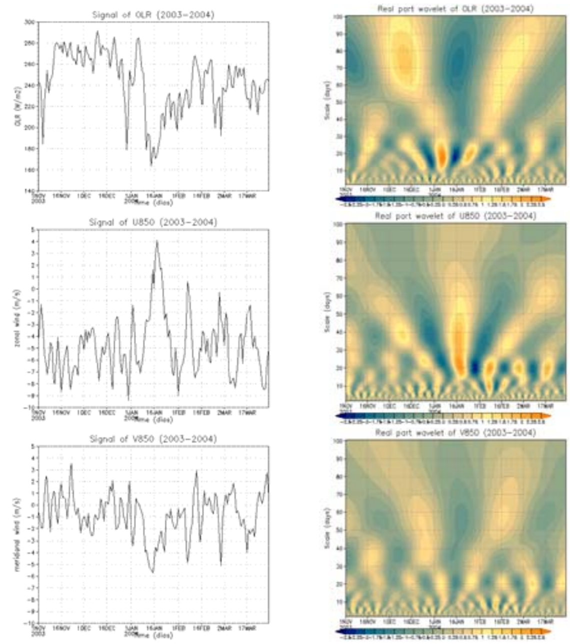


Figure 7. Scalograms of the real part of wavelet (right hand panels) for OLR (top), U850 (middle) and V850 (bottom) over NeB and its respective signals (left hand panels).

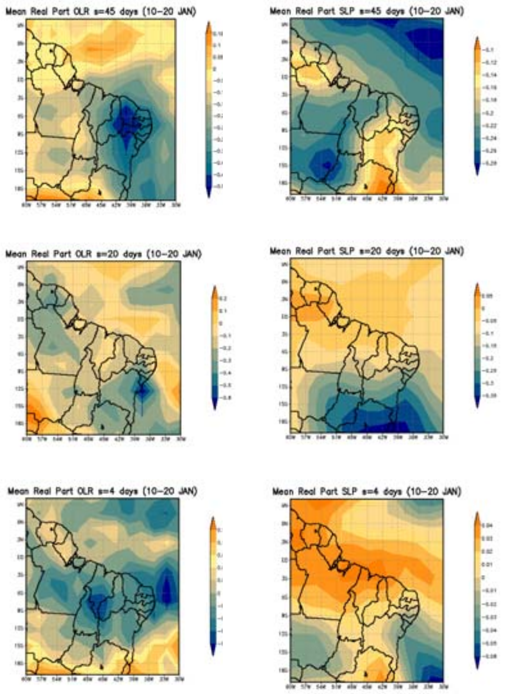


Figure 8. Average fields of the real part of wavelet for OLR (left panels) and SLP (right panels) for the period of 10-20 January 2004 in the time scales of 45 days (top), 20 days (middle) and 4 days (bottom).

4. DISCUSSION AND CONCLUSIONS

This study focused on the intense precipitation observed during the austral summer 2003-2004 over Northeast Brazil, and possible mechanisms contributing to the event. The method of Morlet wavelet transform was applied to daily meteorological data to characterize the temporal oscillations that affected the region during the season. The results show that rainfall in NeB was related to the PNA and AAO, with time scales of 60, 30 and 20 days that contributed to observed OLR and SLP variability in the region on time scales of 60, 45, 30, 20 and 4 days.

The diagnosis of the signals of the PNA and the AAO showed intense intraseasonal modulation during the period of December 2003-February 2004 that favored the organization of the convection over the region. The intraseasonal signal of OLR and SLP reached the NeB through teleconnections with the SPCZ and PNA pattern. Although January 2004 featured ENSO-neutral conditions in equatorial Pacific, there is some evidence that anomalous convection over the tropical Pacific in December provoked a La Niña-like pattern, contributing to a negative PNA pattern that influenced NeB during early January. An intense SPCZ during December and January was a precursor to the intense convective outbreak over NeB during January. Moreover, the oscillations of OLR and SLP at time scales of 20 and 4 days appear to have been related to the presence of SACZ, FS and ULCV, which combined with the intraseasonal oscillations of 45 days to produce enhanced convective activity and heavy precipitation in the Northeast.

In short, this work demonstrates that a number of meteorological systems superposed on low-frequency (intraseasonal) oscillations related to different teleconnection patterns (Pacific/ North America and SPCZ) affected NeB in distinct periods, resulting in the extreme precipitation observed during January 2004.

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