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# Impact of high potential vorticity intrusions into the tropical upper troposphere in South Atlantic on precipitation over northeast Brazil

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[1] Interannual variations of high potential vorticity intrusions at 10°S in the upper troposphere during NDJFM are shown to be negatively correlated with rainfall over northern northeast Brazil (NEB). That is, higher intrusions associated with stronger equatorial westerlies may provoke droughts. Higher intrusions lead to the formation of an anomalous cyclonic vortex over NEB, which causes convergence in the upper troposphere and sinking motion at lower levels. The number of intrusions in NDJFM has highest correlation, significant at 99% confidence level, with the rainfall of the principal rainy season in FMAM. **Citation:** Rao, V. B., S. H. Franchito, and T. F. Barbosa (2007), Impact of high potential vorticity intrusions into the tropical upper troposphere in South Atlantic on precipitation over northeast Brazil, *Geophys. Res. Lett.*, *34*, L06704, doi:10.1029/2006GL027873.

## 1. Introduction

[2] A quasi-stationary trough forms over equatorial South Atlantic and adjoining Northeast Brazil (NEB) in the upper troposphere during the austral summer and autumn seasons [*Virji*, 1981]. Associated with the trough equatorial westerlies occur. While discussing the origin of the upper tropospheric cyclonic vortices over NEB, which form during this period, *Rao and Bonatti* [1987] suggested that these equatorial westerlies are favorable for extra-tropical tropical interactions.

[3] Austral summer and autumn seasons are the principal rainy seasons for the drought prone NEB. Large interannual variations of rainfall over NEB in some years lead to severe droughts, which have serious social implications. *Moura and Hastenrath* [2004] showed that empirical forecasting of NEB seasonal rainfall does better than the forecasting with numerical models. Northern NEB rainfall seems to be a target most suitable for empirical prediction compared to rainfall of any other place. Empirical forecasts have high performance with pre-seasonal rainfall as the most important predictor. The pre-seasonal rainfall is connected broadly to the surface large-scale processes such as the position and intensity of Inter-Tropical Convergence Zone as originally suggested by *Hastenrath and Heller* [1977]. Surface processes are connected to the tropospheric circulation. Thus, the upper tropospheric processes which are related to the interannual rainfall variation of NEB need to be investigated.

[4] Upper tropospheric equatorial westerlies act as "ducts" and are favorable for extra-tropical tropical interactions. Several authors have shown that stationary linear Rossby waves propagate through westerlies and cross equatorial propagation is possible through westerly ducts [*Webster and Holton*, 1982; *Hoskins and Ambrizzi*, 1993; *Thomas and Webster*, 1994]. If Rossby waves are of sufficiently large amplitude "wave breaking" can occur resulting in reduced meridional propagation which can lead to mixing of subtropical and tropical air. *Waugh and Polvani* [2000] made a climatological study of these "intrusion" events of high potential vorticity (PV).

[5] Tropical rainfall is essentially episodic in nature and a few episodes or lack of them determine the seasonal rainfall [*Riehl*, 1954, p. 95]. Since the occurrence or absence of a few episodes determine the seasonal rainfall to be above or below the normal, these few episodes in turn determine anomalies of seasonal fields such as divergence and vertical velocity. Episodes of intrusions of high PV into the tropics are known to affect tropical convection and rainfall [*Kiladis and Weickmann*, 1992; *Kiladis*, 1998; *Waugh and Funatsu*, 2003]. Thus episodes of intrusions are related to the tropical rainfall episodes in regions where intrusions occur. NEB is one such region. So seasonal mean fields of divergence and vertical velocity are expected to be related to the number of intrusions. Indeed, as we shall show later, interannual variations in the number of intrusions in the upper troposphere are strongly related to the seasonal divergence and vertical velocity, which determine the rainfall. The purpose of the present paper is to study the importance of interannual variations in the number of intrusions on rainfall over NEB.

## 2. Data and Methodology

[6] Normalized rainfall departures the period 1980–1998 for the NEB were obtained for 29 stations from Instituto Nacional de Meteorologia (INMET) and Agência Nacional de Energia Elétrica (ANEEL). Normalized rainfall departures were calculated in the same way as in the work of *Rao et al.* [1997]. These stations are located in the north NEB. The number of intrusions over the South Atlantic Ocean in each year was obtained from *Waugh and Polvani* [2000, Figure 2d]. The number of intrusions are at 10°S and are for the period November, December, January, February and March (NDJFM). The number of intrusions in NDJFM are correlated with the normalized rainfall departures over NEB.

[7] Atmospheric circulation data for the period 1980–1998 were obtained from NCEP/NCAR reanalysis data sets (available http://www.cdc.noaa.gov). The data obtained are zonal and meridional winds, temperature and vertical

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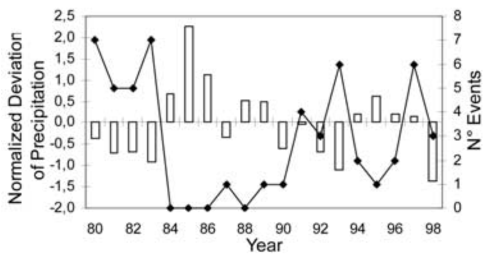


**Figure 1.** Histogram of the normalized deviation of rainfall (for FMAM) and the number of intrusion events obtained by *Waugh and Polvani* [2000] over the South Atlantic.

velocity. Isentropic potential vorticity is calculated using the method given by *Holton* [1992].

## 3. Results

[8] Figure 1 shows the histogram of the normalized deviation of rainfall (for FMAM) and the number of intrusion events obtained by *Waugh and Polvani* [2000] over the South Atlantic. It can be seen from Figure 1 that in general precipitation is higher (lower) when the intrusion events are lower (higher). In an earlier study *Hastenrath* [1990] showed that the precipitation of an earlier period, October through January, is the most powerful predictor accounting for 52% of the interannual March through September rainfall variance. This suggests that the number of intrusions in NDJFM influences rainfall in this season which in turn affects the rainfall in FMAM. Table 1 shows the correlation coefficients between the number of intrusions and the precipitation over NEB for different periods. Also shown is the percentage contribution of rainfall during different periods for the total annual rainfall calculated separately. For example, 68.2% of annual rainfall falls during the period JFMA. As can be seen from the Table 1, all the correlations are negative, that is higher the number of intrusions lesser will be the rainfall and vice-versa. Most of the correlations are significant at 95% level or more. The highest correlation period, FMAM, explains 62% of the variance in annual precipitation over NEB. It is interesting to note that the highest correlation is found for FMAM, which is significant at 99% confidence level. This shows that the intrusions in NDJFM have highest correlation for the period ahead. A probable way by which pre-season rainfall may influence the rainfall of the later season is by increasing soil moisture. Higher soil moisture seems to favor higher rainfall [*Shukla and Mintz*, 1982]. Soil moisture has an important property of retaining anomalous climate signals that can persist for several seasons. Thus soil moisture might be effective in contributing to long term atmospheric variability over land by passing its relatively slow anomalous signals to atmosphere. In a recent study, *Liu* [2003] found that soil moisture patterns have closer relationships to subsequent precipitation variability [see *Liu*, 2003, and references therein]. Thus the high predictability of pre-season rainfall over NEB suggests a cooperation of pre-seasonal circulation departures with pre-moistening of land surface.

[9] The events of intrusions are characterized by the cyclonic circulation towards the equator on the downstream side. Figure 2 shows one such case of intrusion for December 1982. The formation of a cyclonic center is clearly seen. Thus if there are more intrusion events in a season it will result in an anomalous cyclonic circulation in the upper troposphere over NEB. This will provoke upper tropospheric convergence and sinking, leading to drought. On the other hand, when the intrusion events are less or absent, the upper tropospheric setting is favorable for normal or higher rainfall. *Kiladis and Weickmann* [1992] and *Kiladis* [1998] noted that upward motion and convection occur ahead of the trough axis. Thus in the case shown in Figure 2 one would expect sinking in the rear of the trough axis over NEB. The enhancement or suppression of convection depends on the location of the trough axis.

[10] We analyzed two composites of higher and lower intrusion years. The years of lower or no intrusion events were 1984, 1985, 1986, and 1995 (composite 1) and the years of high intrusion events were 1980, 1983, 1993, and 1997 (composite 2). Figures 3a–3d show respectively the zonal wind, anomalies (deviations from the mean of 1980–1998) of vector wind, horizontal divergence at 200 hPa, and vertical velocity $\omega$ at 500 hPa for NDJFM of the composite 1 of higher rainfall (lower number of intrusions). Figure 3a shows that the zonal wind near equatorial regions is weak and Figure 3b shows straight easterly flow over NEB. Figure 3c shows divergence over NEB and Figure 3d shows rising motion at 500 hPa over NEB. This divergence at 200 hPa and the related rising motion seem to be responsible for the higher precipitation. Figures 3e–3h show the corresponding values of zonal wind, anomalies of vector wind, divergence at 200 hPa and $\omega$ at 500 hPa for NDJFM of the composite 2. In contrast to the previous composite, the westerly zonal wind over near equatorial regions is more than 10 m s$^{-1}$, which is more than double of the previous value. This high westerly zonal wind acting as a duct seems to permit higher intrusions, as seen in Figure 1 during 1993. This is mentioned by several authors [*Webster and Holton*, 1982; *Thomas and Webster*, 1994]. Figure 3f shows a clear cyclonic vortex over NEB. This cyclonic vortex is associated with convergence and sinking motion, as can seen in Figures 3g–3h. Thus higher intrusions seem to provoke the formation of a cyclonic vortex and the associated sinking motion. So, the interannual variations of rainfall over NEB are strongly related to the interannual variation of number of intrusions in the upper troposphere. In an earlier study, *Hastenrath and Greischar* [1993] found that Atlantic sea surface temperature anomaly patterns hydrostatically control the atmospheric thickness and thus upper tropospheric wind field which shows westerly anomalies at 10°S during NEB dry years. Here we identified a mechanism which

**Table 1.** Correlation Coefficients Between the Number of Intrusions and the Precipitation Over NEB for Different Periods[a]

| Period | Correlation Coefficient | Annual Precipitation, % |
|---|---|---|
| NDJFM | −0.40 | 64.1 |
| JFMA | −0.52[b] | 68.2 |
| FMAM | −0.64[c] | 62.2 |

[a]Also shown is the percentage contribution of rainfall to the variance of annual rainfall. The period record is 1980–1998.
[b]Confidence level of 95%.
[c]Confidence level of 99%.

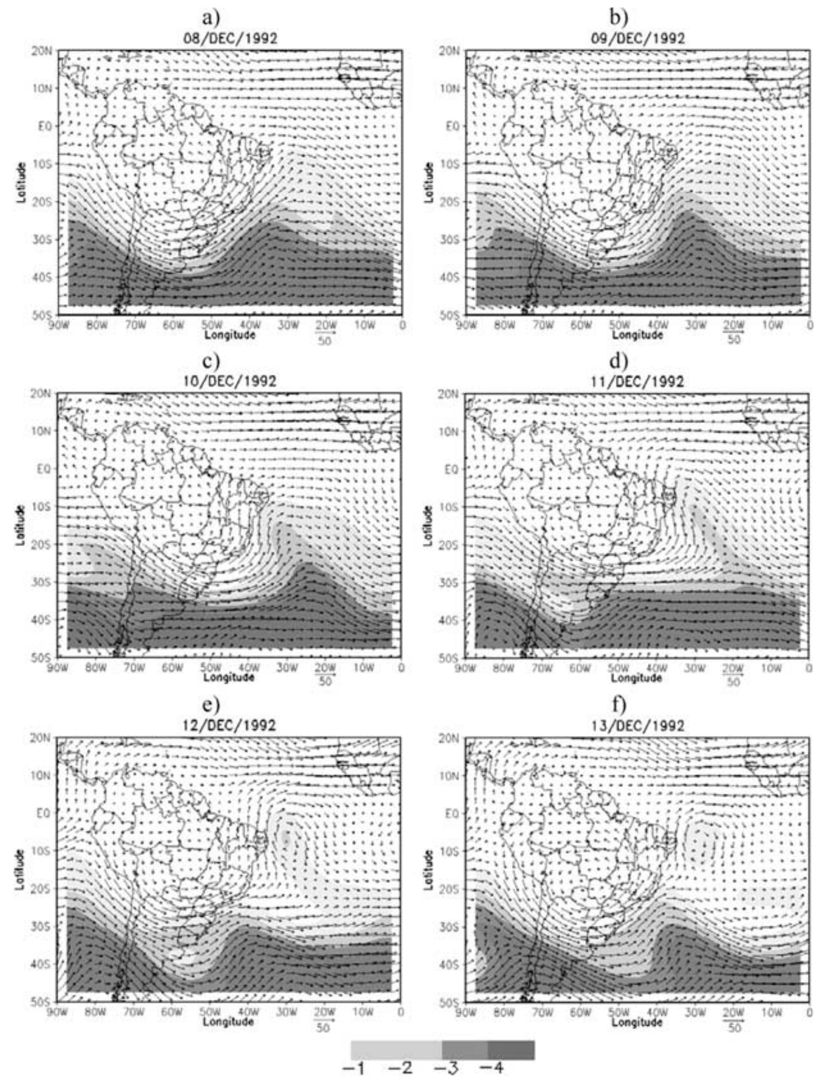


**Figure 2.** Vector wind (m s−1) at 200 hPa. The shadowed region is for isentropic potential vorticity ($10^{-6}$ K $m^2$ $s^{-1}$ $kg^{-1}$) at 350 K. The scales of wind and potential vorticity are also shown.

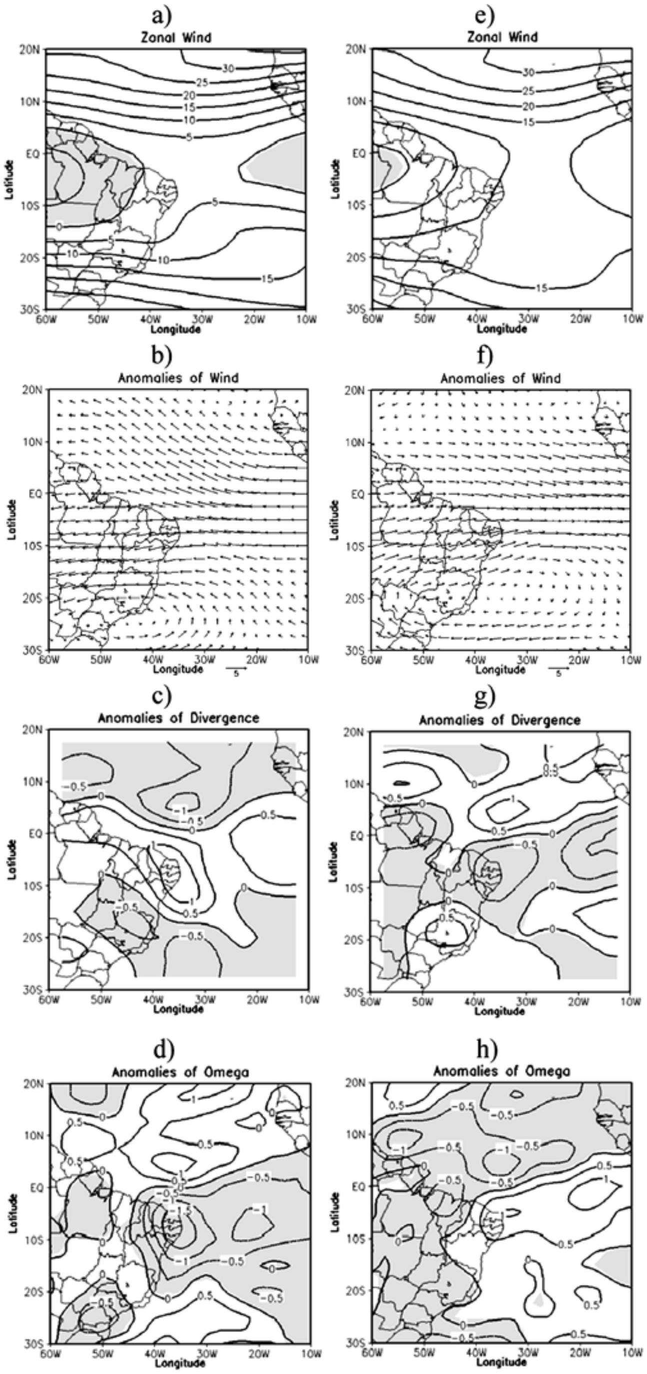


**Figure 3.** (a) Zonal wind, (b) anomalies of vector wind, (c) horizontal divergence at 200 hPa, and (d) vertical velocity $\omega$ at 500 hPa for the composite 1 of lower intrusions; (e–h) Same as Figures 3a–3d but for the composite 2 of high intrusions.

connects both variations in westerlies and so the intrusions to the upward motion and rainfall. Thus our results complement their study.

## 4. Conclusions

[11] In this study it has been found that the interannual variations of intrusions at 200 hPa over South Atlantic are related to the interannual variations of seasonal rainfall over NEB. Higher intrusions associated with stronger equatorial westerlies seem to accompany droughts while lack of intrusions with weak westerly winds facilitates the occurrence of higher rainfall. The physical mechanism which causes these variations seems to be the following: higher equatorial westerly wind acts as a duct, as mentioned by several authors, and accompany higher intrusions which favor the formation of an anomalous cyclonic vortex that generates convergence in the upper troposphere and sinking motion. This inhibits the formation of convection and rainfall. While during the years of weak westerly winds lack of intrusions favor higher rainfall. Thus we identified a new upper tropospheric setting which has a bearing on seasonal rainfall, which explains 62% of the variance of annual rainfall.

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