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SHORT CONTRIBUTION

On the possibility of barotropic instability over northeast Brazil

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The easterly zonal wind profile over northeast Brazil during the rainy season of a heavy rainfall year satisfies the necessary condition for the existence of barotropic instability. The wave with a wavelength of 1250 km has the highest growth rate, $1.6 \times 10^{-6}\ s^{-1}$ (*e*—folding time of about 6 days). The zonal wind profile is found to be stable during a dry year. This suggests that it is likely that barotropic instability might contribute to the interannual variations of rainfall over northeast Brazil.

1. Introduction

Northeast (NE) Brazil is characterized by highly variable interannual rainfall. The deficiency of rainfall in this region often leads to severe drought conditions. There are a few studies which describe the general climatology of this region including the rainfall characteristics (Ratisbona, 1976; Hastenrath and Heller, 1977; Kousky and Chu, 1978; Kousky, 1979, 1980). The rainy season over most of NE Brazil is rather short and occurs in March, April and May (Strang, 1972; Moura and Shukla, 1981). This is related to the position of the intertropical convergence zone, ITCZ, which has its southern most position at this time. There are interannual variations in the latitude of the southward penetration of the ITCZ (Hastenrath and Heller, 1977). Further, Marques et al. (1983) noted changes in the structure of the lower tropospheric easterlies during 2 years of contrasting rainfall over NE Brazil. Westward moving disturbances are noted in tropical easterlies and the presence or absence of these disturbances determines in general, the flood or drought (Riehl, 1954). Thus during the years of normal or heavy rainfall one could expect atmospheric conditions favorable for the development of disturbances. Nitta and Yanai (1969) suggested that the disturbances observed in the Marshall Islands (9.00° N, 168.00° E) region are due to barotropic instability of the easterly zonal current found in the vicinity of the ITCZ. The situation over NE Brazil seems to be similar to that found by Nitta and Yanai. The purpose of the present note is to examine the possible role of barotropic instability in the interannual variations of rainfall over NE Brazil.

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2. Barotropic instability problem

Stability characteristics of barotropic zonal currents in the atmosphere have been studied by several authors; for instance, Kuo (1949), Platzman (1952), Yanai and Nitta (1968), Nitta and Yanai (1969). Haltiner (1963) and Yanai and Nitta (1968) developed a finite difference method for solving the barotropic instability problem. This is done using the linearized barotropic non-divergent vorticity equation. Assuming that the stream function ψ is

$$\psi = \phi(y)\, e^{i\mu(x-ct)} \quad (1)$$

where $\phi(y)$ is the amplitude, we will have

$$(U-c)\left(\frac{d^2\phi}{dy^2}-\mu^2\phi\right)+\left(\beta-\frac{d^2 U}{dy^2}\right)\phi=0 \qquad (2)$$

where μ is the wave number and c is the complex phase speed, $c = c_r + ic_i$. Eq. (2) can be written in finite difference form

$$(U_k - c)\left[(\phi_{k-1} + \phi_{k+1} - 2\phi_k)/(\Delta y)^2 - \mu^2 \phi_k\right] + \left[\beta - (U_{k-1} + U_{k+1} - 2U_k)/(\Delta y)^2\right] \phi_k = 0. \qquad (3)$$

where Δy is the distance between two grid points k and $k + 1$. At the boundaries $y = 0$ and $y = 2b$, the amplitude ϕ is required to vanish. When applied to all grid points in the interval 0 to $2b$ eq. (3) gives the matrix relation

$$(B - cD)\,\phi = 0$$

where $(B - cD)$ and ϕ are the coefficient matrix and a column vector, respectively. If D is non-singular the condition for a non-zero solution of ϕ is

$$\mathrm{Det}\,(D^{-1} B - cI) = 0 \qquad (5)$$

where D^{-1} is the inverse of D and I the unit matrix. Thus the phase velocities c are the eigenvalues of the matrix $D^{-1} B$. The growth rates (μci) can be determined knowing c.

Before discussing the characteristics of the zonal currents over NE Brazil, it would be worthwhile to repeat some of the known results as a check. Thus the stability properties of the zonal currents given by Nitta and Yanai (1969), their eqs. (5) and (6) are calculated. The agreement between our calculations and their results (their Figs. 1 and 2) was excellent.

3. Barotropic instability of the observed easterly zonal current

We will now examine the possible barotropic instability of the observed easterly zonal current over NE Brazil for two constrating years. In order to select the wet and dry years, 58 raingauge stations which are uniformly distributed in the NE Brazil were examined for the period 1971–78. It was found that 1974 and 1976 were years of excessive and deficient rainfall respectively. Further details of rainfall analyses were given in Marques et al. (1983). Fig. 1 shows the latitudinal distribution of the average zonal wind (top panel) and the absolute vorticity (bottom panel) for the rainy season, March, April and May 1974 and 1976 at 850, 700 and 500 mb levels. These profiles were obtained using data from 11 rawin and one pilot balloon stations and represent conditions along 41° W approximately. During the wet year 1974, at 850 and 700 mb levels the gradient of absolute vorticity changes its sign and the necessary condition for the barotropic instability is thus satisfied.

The barotropic instability of the 850 mb zonal wind of 1974 was analysed using the finite difference method of Yanai and Nitta (1968). Fig. 2 shows the growth rate (μc_i) in units of 10^{-6} days. Following Yanai and Nitta (1968) we included more than 20 subdivisions in the interval 2–22° S. Boundary conditions were imposed at 2° and 22° S. It should be remarked that the boundary conditions used are somewhat arbitrary. From Fig. 2 it can be seen that the wave with a wavelength of 1250 km has the highest growth rate, 1.6×10^{-6} s^{-1} (*e*-folding time of about 6 days). This wave has an easterly phase speed of 2.7 m s^{-1}. If the daily or monthly mean velocity profiles were used the growth rate of the unstable wave could be larger. However, number of missing observations of the stations over NE Brazil are generally large and no attempt is made here to use the profiles for shorter time intervals.

From Fig. 1 it can be seen that during the dry year 1976, the absolute vorticity increases monotonically with decrease of latitude and the necessary condition for occurrence of barotropic instability ($\beta - d^2 u/dy^2 = 0$) is not met. Thus the zonal wind distribution is unfavorable for the growth of the disturbances.

4. Concluding remarks

Observed zonal wind profiles over NE Brazil during the rainy season (March, April and May) of heavy rainfall and dry years were examined for barotropic instability. It was found that during the wet year 1974, the easterly zonal wind was unstable. During the dry year 1976, the zonal wind was found to be stable. Thus it can be concluded that barotropic instability seems to play an important role in the interannual variations of rainfall over NE Brazil.

Regarding the other possible mechanisms for the amplification of the disturbances over NE Brazil,

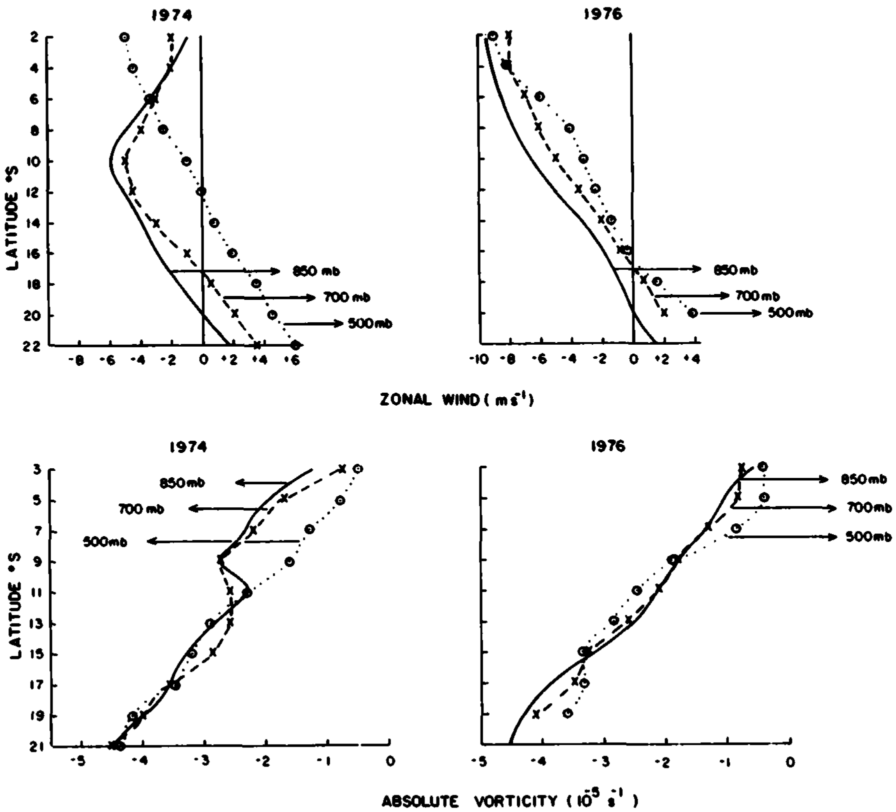

Fig. 1. The Zonal wind and the corresponding absolute vorticity observed over Northeast Brazil during March, April and May 1974 and 1976.

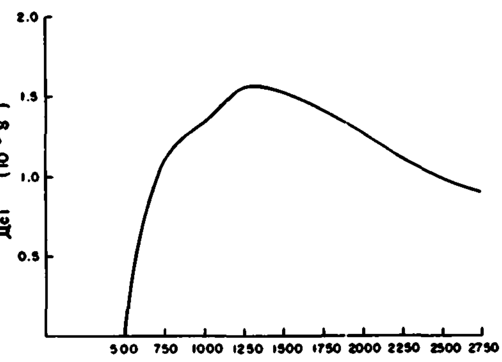

Fig. 2. Growth rate of the unstable disturbances for the 850 mb zonal wind profile of 1974.

heating by convective clouds may play some role. In an earlier study, it has been found by one of the authors (Marques, 1981) that the thermodynamic structure of the atmosphere over NE Brazil during the rainy season is similar to that found over other tropical regions, where heating by convective clouds is known to play an important role.

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