SOME ASPECTS OF THE VARIABILITY OF THE ATMOSPHERE OVER NORTHEAST BRAZIL

Valdo da Silva Marques
Instituto de Geociências,
Universidade Federal do Rio de Ja
Janeiro, Brasil, and

V. Brahmannanda Rao,
Insituto de Pesquisas Espaciais/CNPq,
São José dos Campos, São Paulo, Brasil.

1. Introduction

Northeast (NE) Brazil is characterized by a dry region whose annual rainfall amounts to a meagre 500 mm. The so-called drought polygon is located somewhat interior in NE Brazil. Most of the previous observational studies regarding the climate of NE Brazil utilized surface data or data from a short series of a few upper air stations. Since the beginning of 70's a reasonably well distributed network of upper-air stations started operating regularly, which permitted a study of the upper-air characteristics.

2. Area of the study and data source

The area of the study is shown in Fig. 1. A cylindrical boundary having 9 RS/Rawin and 2 pilot balloon stations is defined. This cylinder, apart from covering most of NE Brazil, facilitates the integration of the equations for estimates of energy, mass and water vapor fluxes. The area enclosed by cylinder is about $10^6 km^2$ and extends in the vertical up to 100 mb, except for the calculation of water vapour flux which extends up to 300 mb.

The data are obtained from the "Monthly Climatic Data for the World" (U.S. Department of Commerce), 1971-78 and missing data are completed with the original data source at the Instituto Nacional de Meteorologia and Instituto de Pesquisas Espaciais, both in Brazil.

3. Precipitation analysis

Rainfall data of 58 rain-gauge stations, which are reasonably well distributed over NE Brazil are examined for the 1971-78 period. Normalized departures of annual precipitation show that 1974 is a year of high rainfall and 1976 a dry year. In order to examine the spational distribution of rainfall for the dry and wet years, the deviation for the principal rainy season (March, April and May) from the normal is expreseed as $D = 100 \times (P_i - \overline{P})/\overline{P}$, where D is the normalized deviation expressed in %, $\overline{P}$ is the normal, P_i is the precipitation for March-April-May of 74 or 76. The normalized deviations are obtained for each station and the isolines are shown in the Figurues 2 and 3. Further details regarding the rainfall analysis can be found in Marques et al (1983).

4. Zonal wind structure

Figures 4 and 5 show the cross sections of the zonal wind component along the meridian 41°30'W, which passes approximately through the centre of the base of cyclinder. There are some clear quantitative differences between these two cases. In the dry year 1976, the easterlies are stronger up to about 400 mb from the surface in the low latitudes, in agreement with that found by Hastenrath and Heller (1977) for the surface. Also the lower level easterlies during the wet year 1974 show a maximum aroung 10°S, decreasing to the north and south. This is in contrast to the structure of the zonal wind during the dry year 1976, which shows a monotonic increase of easterlies in the lower levels towards lower latitudes. In a recent study by the authors (Rao et al, 1984) it has been found that the zonal wind profile during the wet year 1974 is favourable for barotropic instability, while the profile during the dry year 1976 is found to be stable.

5. Static energy

The static dry energy ($c_pT + gz$) and the static moist energy ($c_pT + gz + Lq$), have been evaluated for the dry and wet years. The details of the calculation may be found in Marques (1981). Fig. 6 shows that the static dry energy increases with height while the static moist energy has a minimum in the lower troposphere with higher values both in the lower and upper levels. This is a well-known characteristic of the tropical atmosphere as presented by Riehl (1979) and his values are shown in the same Figure.

Further it can be noted from Fig. 6 that the humidity values are higher during the wet year and the vertical gradient of ($c_pT + gz + L_q$) during the wet year is almost constant in the middle troposphere from about 800 mb up to 500 mb. A somewhat similar feature is also seen in Riehl's values for the equatorial trough zone. It is known that during the wet year the equatorial trough is closer to NE Brazil (Hastenrath and Heller 1977). This suggests that during the wet year there is mixing, perhaps due to the disturbances which is favourable for the convection and consequently to the precipitation.

6. Mass, engergy and water vapour flux

All the inward and outward fluxes estimated for northeast Brazil are proportional to the normal component (V_n) relative to the lateral surface of the cylinder. Fig. 7 shows that during the wet year, there is an inward mass flux (V_n negative) in the lower levels and an outward mass flux in the upper levels. During the dry year, there is an inward mass flux in the middle levels with an outward mass flux above and below. The convergence in the middle levels forces a subsidence in the lower levels. This seems to be the mechanism which inhibits the development of clouds and precipitation.

The tatol engery flux can be calculated from the equation:

$$H_S + H_R + LE = \frac{R}{G}\oint\int_{P_T}^{P_o} (c_pT + gz + Lq)\, V_n\, d\xi\, dp$$

where the symbols have the following meaning: H_S = sensible heating; H_R = net radiational cooling; LE = latent heating; P_T = 100 mb for the energy flux and equal to 300 mb for water vapour flux; P_o = surface pressure; R = radius of the cylinder; g - acceleration of gravity; L = heat of condensation; q = specific humidity; V_n = normal velocity; ξ = azimutal angle; p = pressure.

Table 1 shows the fluxes of ($c_p\bar{\bar{T}} + g\bar{\bar{z}}$), $L\bar{q}$ and ($c_p\bar{T} + g\bar{z} + L\bar{q}$), respectively, for wet and dry years. The profiles in both the cases have approximately the shape of the normal velocity profile. During the wet year 1974, there was import of sensible heat at all levels except the top two levels. During the dry year 1976, there was export at lower levels and import at higher levels, and again import at the top-most level.

Although, there is a small net export in both the years, the import and export values at different levels are larger in 1976. The main difference is found in the water vapour flux. During the wet period there is a net import of 6.1×10^{13} J/s of water vapour, while the dry period presented a net export of 11.2×10^{13} J/s. Considering the cylinder area as 11.31×10^{15} cm, the second case corresponds to an excess of evaporation over precipitation of about 4 mm/day.

Since the rainfall in this region occurs mainly in the months of March, April and May (for which the calculations are made) the water vapour loss of this order should be considered serious. During the wet year 1974, the import of water vapour corresponds to an excess of precipitation over evaporation of about 2.1 mm/day. This again shows that even during a heavy rainfall year, the evaporation rate is high such that the water availability in the soil during the rest of the year is small.

7. Conclusion

An examination of vertical profiles of energy and water vapour flux for the dry and wet cases showed that the vertical structure is similar to that found for the equatorial trough zone. The proximity of the equatorial trough during a wet period is also connected with weakening of easterlies which is associated with the structure of normal velocity favourable for precipitation. Thus, it seems that the interannual variability of rainfall in NE Brazil is not of local origin but is connected with the variability of general circulation in the tropics.

The water vapour flux calculations show that in rainy season of the dry year the loss of water vapour amounts to 4 mm per day.

REFERENCES

HASTENRATH, S. and HELLER, L., 1977: Dynamic hazards in northeast Brazil. *Quart, J. Roy. Meteor. Soc.*, 103, 77-92.

MARQUES, V.S., 1981: *Estudos da energética e do fluxo de vapor d'água na atmosfera sobre o nordeste do Brasil (Studies of energetics and water vapor flux in the atmosphere over northeast Brazil)*. Ph.D. Thesis. Instituto de Pesquisas Espaciais. São José dos Campos, SP, Brasil, 182 p.

MARQUES, V.S.; RAO, V.B. and MOLION, L.C.B., 1983: Interannual and seasonal variations in the structure and energetics of the atmosphere over northeast Brazil. *Tellus*, 35A, 136-148.

RAO, V.B.; MARQUES, V.S. and BONATTI, J.P., 1984: On the possibility of barotropic instability over northeast Brazil. *Tellus*, 36A, 207-210.

RIEHL, H.; 1979: Climate and weather in the tropics. Academic Press, New York, 611 p.

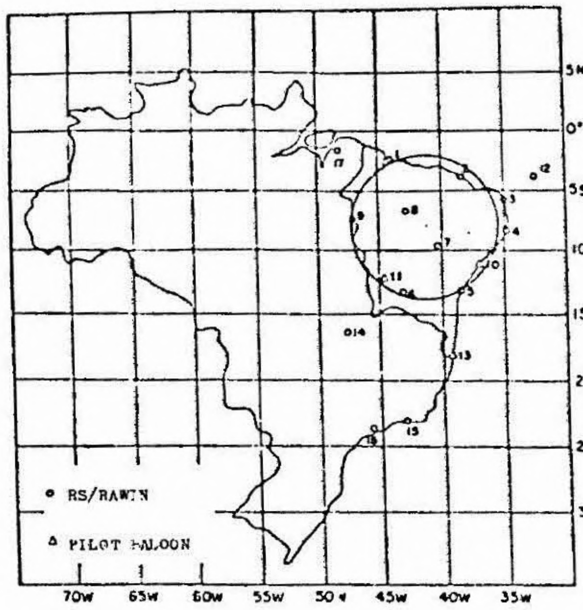

Fig. 1 - Stations location and the definition of cylinder over Northeast Brazil

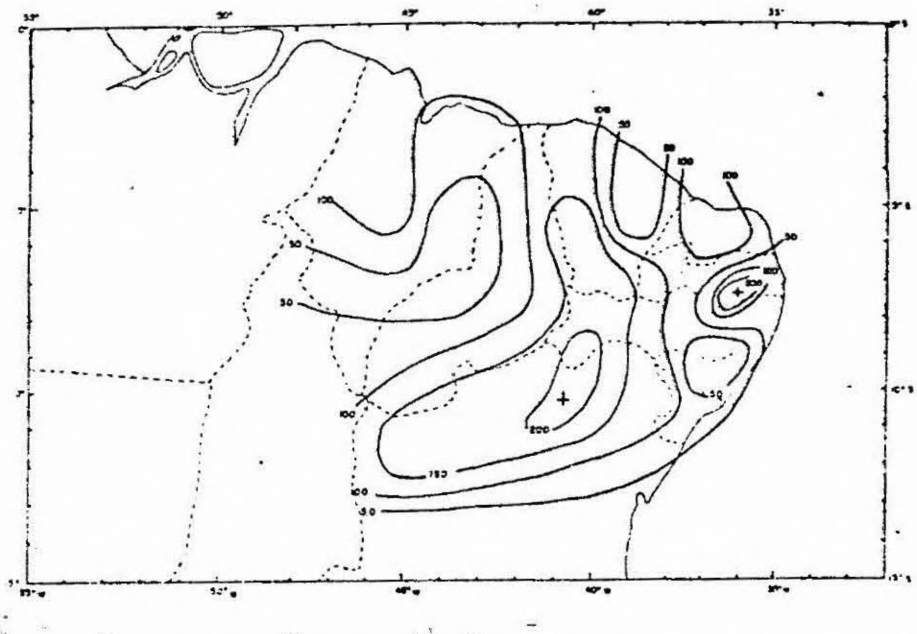

Fig. 2 - Normalized deviations of rainfall for March-April-May of 1974

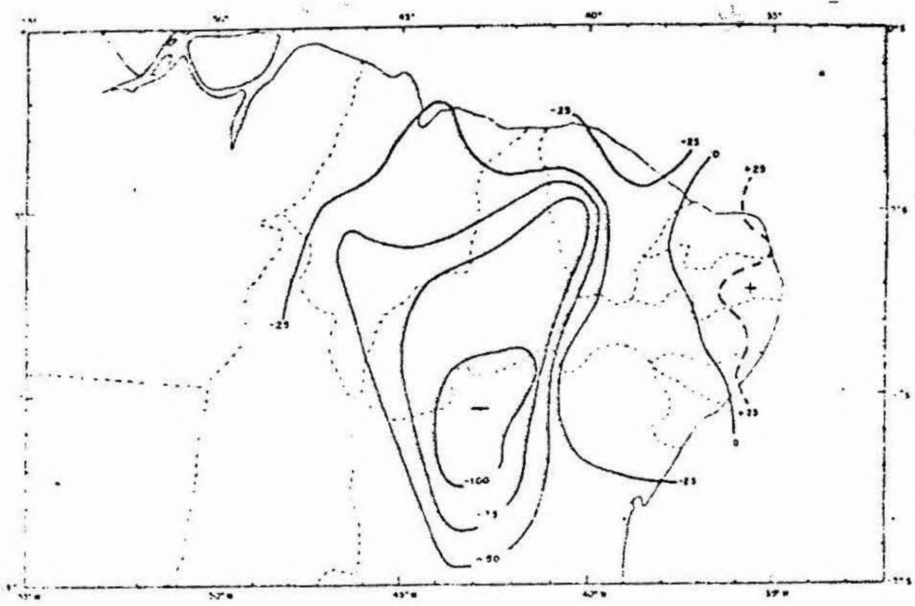

Fig. 3 - Normalized deviations of rainfall for March-April-May of 1976

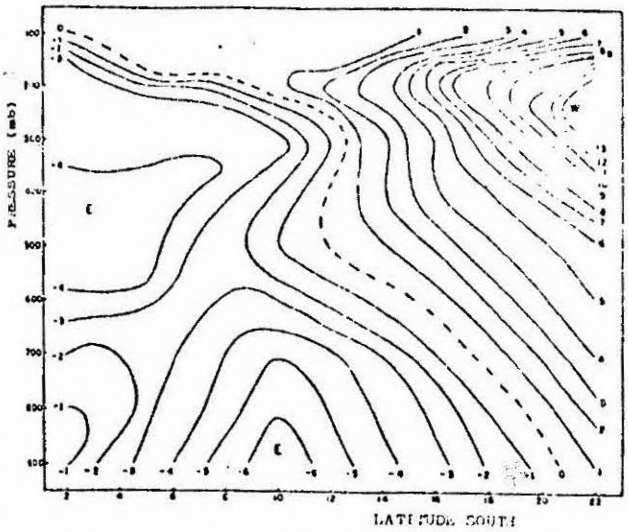

Fig 4 - Zonal wind component in a cross section along approximately 41°W. March-April-May 1974

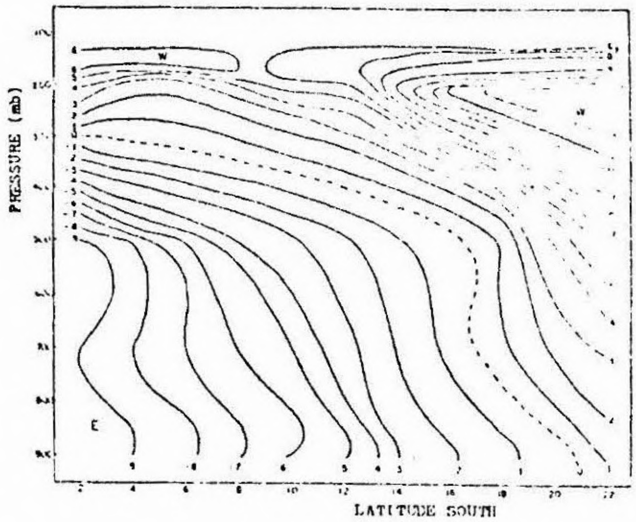

Fig 5 - Zonal wind component in a cross section along approximately 41°W, March-April-May 1976.

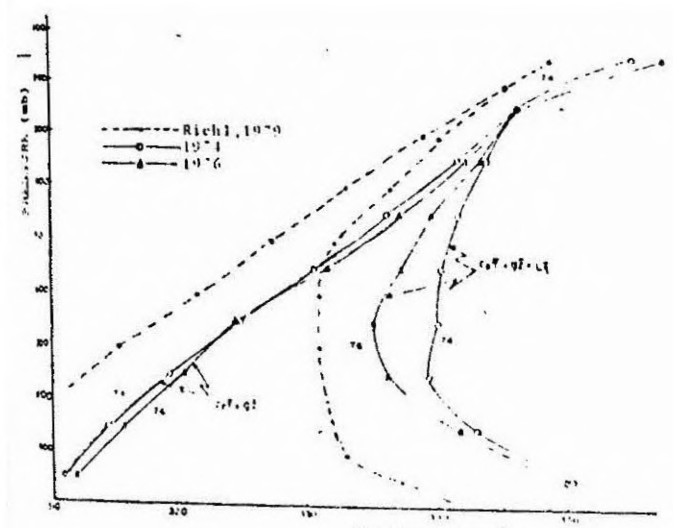

Fig 6 - Vertical profiles of (C_pT + gz) and (C_pT + gz + Lq) for the wet seasons of 1974 and 1976.

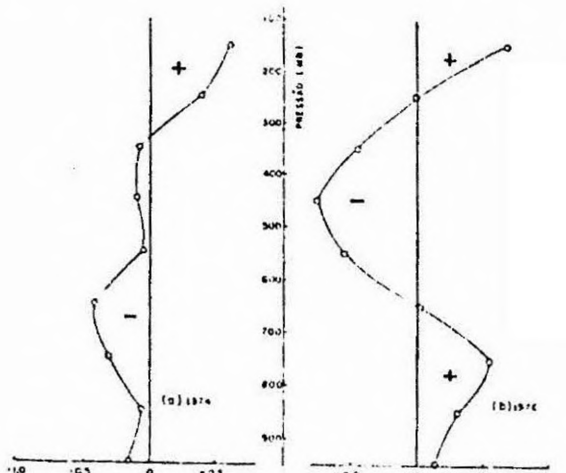

Fig 7 - Vertical profile of the component of wind normal to the boundary of the cylinder for the wet seasons of 1974 and 1976. Negative values indicate inward component.

Table 1 - Interannual variations of energy fluxes by the motion. Negative values indicate inward flux. (10^{13} J/s).

Pressure (mb)	1974			1976		
	c_pT+gz	Lq	$c_pT+gz+Lq$	c_pT+gz	Lq	$c_pT+gz+Lq$
Sfc-900	-36.8	-3.4	-40.2	+29.7	+2.9	+32.6
900-800	-13.9	-0.5	-14.4	+70.0	+3.7	+73.7
800-700	-69.5	-1.8	-71.3	+124.0	+4.4	+128.4
700-600	-98.2	-1.9	-100.1	+7.1	+1.1	+8.2
600-500	-1.0	+0.6	-10.4	-128.3	-0.4	-128.7
500-400	-23.8	+0.6	-23.2	-154.6	-0.4	-155.0
400-300	-21.3	+0.3	-21.0	-106.7	-0.1	-106.8
300-200	+116.9	--	+116.9	-4.9	--	-4.9
200-100	+165.7	--	+165.7	+170.7	--	+170.7
Total	+8.1	-6.1	+2.0	+7.0	+11.2	+18.2