Water Vapor Characteristics over Northeast Brazil during Two Contrasting Years

VADLAMUDI BRAHMANANDA RAO AND VALDO DA SILVA MARQUES[1]

Instituto de Pesquisas Espaciais-INPE, Conselho Nacional de Desenvolvimento Científico e Tecnológico-CNPq, São Paulo, Brazil

(Manuscript received 16 June 1983, in final form 23 December 1983)

ABSTRACT

Water vapor characteristics over northeast Brazil for two contrasting years are discussed. During the wet year 1974, the precipitation efficiencies were less than 20% over the interior dry region and during the dry year 1976, they were reduced to 10% or less. The reduction is mainly due to low precipitation in 1976. Calculation of water vapor flux showed that in both wet and dry years, the flux is inward in the east sector and outward in the west sector. This suggests the importance of the South Atlantic Ocean in providing water vapor for NE Brazil. During the wet year, the lower tropospheric flow is convergent and in the northwest part, the direction of flow is more northerly/less southerly. During the dry year the opposite occurred. This indicates the possible role of the Intertropical Convergence Zone in the interannual variations of climate over NE Brazil.

1. Introduction

The interannual variation of the climate of northeast (NE) Brazil, as revealed by the large rainfall variability, forms not only a curious scientific problem but also has important socio-economic implications. This region is haunted by recurring droughts and the agriculture based economy is seriously affected when prolonged periods of drought occur. During the drought years harvest reduces almost to nil and the region requires emergency measures.

Early studies described the general climatology of the region including the rainfall characteristics (Strang, 1972; Ratisbona, 1976; Hastenrath and Heller, 1977; Kousky and Chu, 1978). The east coast of NE Brazil receives about 2000 mm of precipitation annually, while the central dry region receives only about 400 mm. The rainy season is centered in March, April and May with almost no precipitation during the remaining nine months (Strang, 1972; Moura and Shukla, 1981). Despite some attempts to delineate atmospheric or oceanic parameters responsible for the interannual variation, the problem of understanding the role of various physical processes at work and of predicting the climatic variations is still far from complete.

Most of the previous observational studies were limited by the lack of well distributed upper-air stations. Since the beginning of the 1970's, a reasonably dense network of upper-air stations started operating regularly in this region. The purpose of the present paper is to study the characteristics of water vapor over NE Brazil during two contrasting years, using these upper-air data.

[1] Also with the Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil.

2. Data and methodology

We define a cylinder whose base covers most of the NE Brazil area. It contains nine radiosonde/rawinsonde stations (Fig. 1). Defining such a cylinder facilitates the calculation of water vapor flux. We used the monthly mean data for the period 1971–78, mostly obtained from the U.S. Department of Commerce (1971–78). In order to select dry and wet years we used precipitation data of 58 raingage stations in NE Brazil which are uniformly distributed. Examining the rainfall data for the 8-year period, 1974 and 1976 are earmarked as wet and dry years, respectively. The data source mentioned above does not include surface wind data. Therefore, surface winds at 19 NE Brazil stations are obtained from the Instituto Nacional de Meteorologia of Brazil for the rainy seasons of 1974 and 1976. The Appendix gives the latitude, longitude and elevation of these stations. Further details regarding the data and the rainfall analysis can be found in Marques *et al.* (1983).

The water vapor conservation equation can be written approximately as

$$\int_{P_T}^{P_0} \nabla\cdot(\langle q\rangle\langle \mathbf{V}\rangle)\frac{dp}{g} = \langle E - P\rangle, \qquad (1)$$

where q is the specific humidity, $\mathbf{V}$ is the horizontal wind vector, and E and P are the evaporation and precipitation, respectively. The angle brackets indicate time mean. In the present case, it is the mean of three months, March, April and May. Here, $P_T = 300$ mb, $P_0 = 1000$ mb and g is the acceleration of gravity. In obtaining (1), the moisture flux due to transient eddies is neglected. Taking area average of (1) we obtain

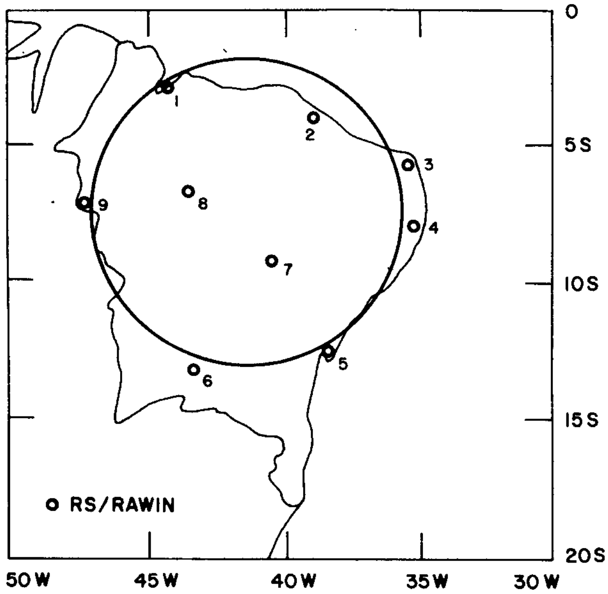

FIG. 1. Station location and the definition of cylinder over northeast Brazil.

$$\int_{P_T}^{P_0} [\nabla \cdot (\langle q \rangle \langle \mathbf{V} \rangle)]_a \frac{dp}{g} = [\langle E - P \rangle]_a, \quad (2)$$

where

$$[\quad]_a = \frac{1}{A} \iint (\quad) dA,$$

and A is the area of the cylinder.

Using the divergence theorem, the left-hand side of (2) can be written as

$$\frac{1}{gA} \int_{P_T}^{P_0} \oint \langle q \rangle \langle V_n \rangle ds dp, \quad (3)$$

where ds is an element of the circumference of the cylinder and V_n is the outward normal component of velocity. Thus, the divergence of water vapor can be calculated using (3). This is done by dividing the lateral surface of the cylinder into nine points in the horizontal with an equal separation of 400 km and seven points in the vertical with an equal separation of 100 mb. Further computational details and the discussion of possible errors can be found in Marques (1981).

In addition to the computations of water vapor flux we propose to calculate the so called "precipitation efficiency" (P.E.). This might show interesting differences in this quantity during the contrasting years. Sellers (1965) defined P.E. as the ratio between mean daily precipitation and the average precipitable water. He suggested that this ratio can be thought of as the fraction of the average moisture overhead which falls as precipitation on an average day. Viswanadham *et al.* (1980) calculated P.E. for the Southern Hemisphere. Following Sellers (1965) we write P.E. as

$$\text{P.E.} = \frac{\text{Precipitation}}{\text{N.D.} \times \text{Precipitable water}} \times 100\%,$$

$$= \frac{\text{P.}}{\text{N.D.} \times \text{P.W.}} \times 100\%. \quad (4)$$

In (4), P. is monthly mean precipitation, P.W. is monthly mean precipitable water and N.D. is the number of days in a month.

Precipitable water is defined as

$$\text{P.W.} = \frac{1}{g} \int_{P_T}^{P_0} q dp. \quad (5)$$

Using (4) and (5) we calculate P.E. for the nine stations in NE Brazil for the rainy seasons of the contrasting years 1974 and 1976. The integral (5) is evaluated using seven points in the vertical at equal separations of 100 mb.

3. Results and discussion

Table 1 gives the monthly mean precipitation, precipitable water and precipitation efficiency for the nine stations. Also given are the stations numbers, as marked in Fig. 1, and the station elevations. Rainfall was generally more in 1974 than in 1976. The changes in precipitable water were small, although 1974 was more humid. Also, precipitable water changes with station location were small in contrast to those of precipitation. Precipitation efficiency was generally high at five coastal stations–Salvador, Recife, Natal, Fortaleza and São Luiz. Except at Recife, all stations showed a decrease in precipitation efficiency from 1974 to 1976. At Petrolina it changed from 11.6% in 1974 to 0.3% in 1976 and the decrease was due to a meager rainfall of 2.5 mm in 1976. The increase at Recife was due to a higher decrease in humidity. The decrease in other interior stations, B. J. Lapa, Floriano and Carolina, was considerable. Lack of observations for 1976 prevented a calculation of precipitable water at Fortaleza. Viswanadham *et al.* (1980) calculated P.E. for January and July using Taljaard *et al.* (1969) data. Their calculations also show, in general, low values for the NE Brazil dry region. However, Viswanadham *et al.* did not discuss interannual variations.

Table 2 shows the water vapor flux in different layers of the cylinder. It can be seen that there was inward flux in the lower layers of the atmosphere and an outward flux in the upper layers during the heavy rainfall year 1974. The opposite was true in 1976. In 1974 there was net inward flux, while in 1976 there was a net outward flux.

Figure 2 is plotted in order to examine the characteristics of water vapor flux at various points of the cylinder. This figure shows the magnitudes of the flux

TABLE 1. Precipitation, precipitable water and precipitation efficiency for northeast Brazil for 1974 and 1976 (March, April and May).

Station number as in Fig. 1	Station name	Elevation (m)	Precipitation (mm)		Precipitable water (mm)		Efficiency (%)	
			1974	1976	1974	1976	1974	1976
1	São Luiz (2°32'S, 44°17'W)	51	732.7	279.1	55.5	45.4	44.0	20.5
2	Fortaleza (3°43'S, 38°33'W)	26	527.3	193.6	51.6	—	34.1	—
3	Natal (5°55'S, 33°15'W)	49	372.0	273.6	44.1	41.1	28.1	22.2
4	Recife (8°8'S, 34°55'W)	19	354.5	314.3	45.9	37.2	25.7	28.2
5	Salvador (13°00'S, 38°31'W)	51	335.1	164.4	43.8	37.3	25.5	14.7
6	B. J. Lapa (13°16'S, 43°25'W)	440	89.9	14.7	46.1	34.6	6.5	1.4
7	Petrolina (9°23'S, 40°30'W)	370	143.4	2.5	41.2	32.4	11.6	0.3
8	Floriano (6°46'S, 43°1'W)	110	276.2	45.2	51.4	40.5	17.9	3.7
9	Carolina (7°20'S, 47°28'W)	183	261.9	136.3	54.1	42.8	16.1	10.6

in the lowest layer (surface–900 mb) at the nine equidistant points mentioned earlier. Since the specific humidity decreases rapidly with height, the flux in the lowest layer is crucial in determining the net fluxes. Except at the northern point 6, there is no change of direction of water vapor flux, although there are large changes in magnitudes at some points. Thus in both years 1974 and 1976, there was inward flux of water vapor in the east sector of the cylinder while in west there was an outward flux. The westward transport of water vapor in both years in the western sector seems to eliminate the possible role of the Amazon region in providing water vapor for NE Brazil. Water vapor for NE Brazil seems to be provided mainly by the Atlantic Ocean in the east. In the wet year 1974 there was inward flux at the northern point 6 and in the dry year 1976 there was outward flux.

TABLE 2. Water vapor flux over northeast Brazil, mean of March, April and May (unit: 10^{-6} kg m^{-2} s^{-1}; negative values indicate inward flux.)

Vertical layers (mb)	1974	1976
400–300	+1.5	−0.5
500–400	+2.2	−1.6
600–500	+2.4	−1.6
700–600	−6.3	+4.3
800–700	−6.3	+15.7
900–800	−3.3	+14.2
SFC–900	−21.1	+6.5
Net	−30.9	+37.0

Lower values of precipitation efficiency at the interior stations compared to the coastal stations are due to lower values of precipitation, with humidity being comparable at both. In other words, there is a lack of precipitation-producing mechanisms in the NE Brazil interior dry region. For example, at Petrolina the precipitation-producing mechanism was only 0.3% efficient in 1976! The change of direction of flux at the northern point 6, associated with convergent flow in the lower levels in 1974, suggests that the precipitation producing mechanism is connected with the Intertropical Convergence Zone (ITCZ). [For the mean location of the ITCZ over the Atlantic Ocean see Hastenrath and Heller (1977) and Hastenrath and Lamb (1977).] Previous studies (Hastenrath and Heller, 1977; Marques *et al.*, 1983) stressed the importance of the ITCZ in the interannual variation of rainfall over NE Brazil. In a recent study, the authors (Rao *et al.*, 1983) have noted one such mechanism associated with the ITCZ, namely, barotropic instability of low-latitude easterlies. The presence or absence of instability is associated with the intensification or decay of precipi-

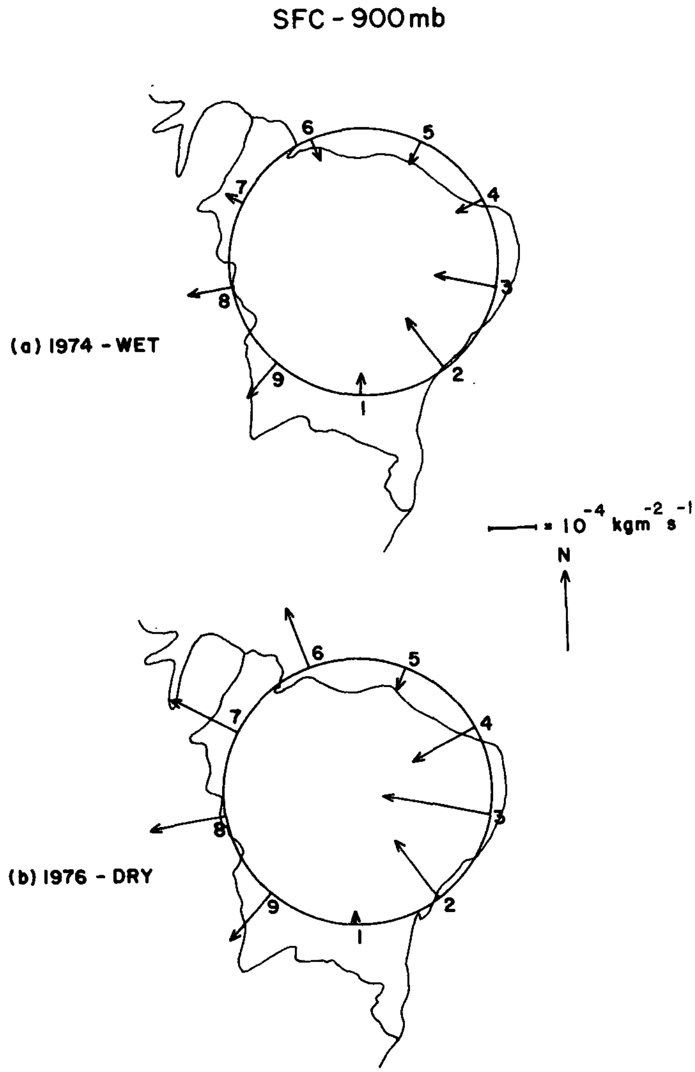

FIG. 2. Water vapor flux in the surface–900 mb layer over northeast Brazil.

tation producing disturbances over NE Brazil, thus explaining the occurrence of wet or dry epochs.

4. Summary and concluding remarks

Precipitation efficiencies are calculated over NE Brazil for two contrasting years, 1974 and 1976. It is found that precipitable water at most of the stations in 1976 was about 80% of its value in 1974, whereas the precipitation was less than 50%. The precipitation efficiency, therefore, was very low in 1976, indicating the inefficiency of precipitation-producing dynamical mechanisms.

Calculation of water vapor flux during the two contrasting years showed that in the east sector of the cylinder there is inward flux of water vapor and in the west there is outward flux. This suggests the importance of the South Atlantic Ocean in providing water vapor for NE Brazil. During the wet year, the lower tropospheric flow is convergent and in the northwest part, it is more northerly/less southerly. During the dry year the opposite is true; this suggests control by the dynamics of large-scale flow.

The present study is based on monthly mean values of wind and humidity. It would be worthwhile to extend this study using daily data which will permit the inclusion of transient processes.

Acknowledgments. Thanks are due to Dr. N. J. Parada for his interest. Thanks are also due to Drs. A. D. Moura and P. Satyamurty for discussions and to Yoshihiro Yamazaki for going through the manuscript.

APPENDIX

Surface Wind Stations.

Station	Latitude	Longitude	Elevation (m)
São Luiz	2°32′S	44°17′W	51
Barra da Corda	5°30′S	45°16′W	82
Parnaiba	2°5′S	41°47′W	22
Terezina	5°5′S	42°49′W	79
Floriano	6°46′S	43°1′W	110
Ceara Mirim	5°39′S	35°25′W	61
João Pessoa	7°7′S	34°53′W	63
F. Noronha	3°51′S	32°25′W	45
Aracaju	10°55′S	37°3′W	10
Remanso	9°41′S	42°4′W	411
Paulo Afonso	9°24′S	38°13′W	249
Salvador	13°0′S	38°31′W	51
Barreirás	12°9′S	45°0′W	435
Lençois	12°34′S	41°23′W	394
Itaberaba	12°32′S	40°18′W	270
B. J. Lapa	13°16′S	43°25′W	440
Caravelas	17°44′S	39°15′W	4
Montes Claros	17°44′S	43°52′W	627
Jaguaquara	13°22′S	39°59′W	755

REFERENCES

Hastenrath, S., and L. Heller, 1977: Dynamics of climatic hazards in northeast Brazil. *Quart. J. Roy. Meteor. Soc.,* **103,** 77–92.

——, and P. Lamb, 1977: *Climatic Atlas of the Tropical Atlantic and Eastern Pacific Oceans.* University of Wisconsin Press, 105 pp.

Kousky, V. E., and P. S. Chu, 1978: Fluctuations in annual rainfall for northeast Brazil. *J. Meteor. Soc. Japan.,* **56,** 457–465.

Marques, V. S., 1981: Estudos da energética e do fluxo de vapor d'água na atmosfera sobre o nordeste brasileiro. (Studies of energetics and water vapor flux in the atmosphere over northeast Brazil). Ph.D. thesis, Instituto de Pesquisas Espaciais, São Paulo, Brazil, 182 pp.

——, V. B. Rao and L. C. B. Molion, 1983: Interannual and seasonal variations in the structure and energetics of the atmosphere over northeast Brazil. *Tellus,* **35A,** 136–148.

Moura, A. D., and J. Shukla, 1981: On the dynamics of droughts in northeast Brazil: Observations, theory and numerical experiments with a general circulation model. *J. Atmos. Sci.,* **38,** 2653–2675.

Rao, V. B., V. S. Marques and J. P. Bonatti, 1983: on the possibility of barotropic instability over northeast Brazil. *Tellus* (in press).

Ratisbona, C. R., 1976: The climate of Brazil. Climates of Central and South America, W. Schwerdtfeger and H. E. Landsberg, Eds., *World Survey of Climatology,* Vol. 12, Elsevier, 219–293.

Sellers, W. D., 1965. *Physical Climatology.* The University of Chicago Press, 272 pp.

Strang, D. M. G. D., 1972: Climatological analysis of rainfall normals in northeastern Brazil. Pap. No. IAE-M02/72. 70 pp. [Available from Centro Técnico Aeroespacial. 12200 São José dos Campos, SP. Brazil.]

Taljaard, J. J., H. van Loon, H. L. Crutcher and R. L. Jenne, 1969: Temperatures, dew points and heights at selected pressure levels. *Climate of the Upper Air: Southern Hemisphere.* Vol. 1, NAVAIR 50-1C-55, Chief of Naval Operations, Washington, DC, 135 pp.

U.S. Department of Commerce, 1971–1978: *Monthly Climatic Data for the World.* [Available from National Climatic Center, Asheville, NC 28801, Attn: Publications.]

Viswanadham, Y., N. J. M. Rao and G. S. S. Nunes, 1980: Some studies on moisture conditions in the Southern Hemisphere. *Tellus,* **32,** 131–142.