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ATMOSPHERIC WATER VAPOUR FLUX AND ITS DIVERGENCE OVER THE DROUGHT PRONE REGION OF TROPICAL NORTHEAST BRAZIL

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The extensive northeast region of Brazil experiences frequent severe droughts that are really catastrophic to the region, like those of 1979 to 1983 (except 1981, considered normal). The present study is a diagnostic one for the mean monthly fields of the atmospheric precipitable water, water vapour flux and its horizontal divergence vertically integrated between the Earth's surface to the level of 300 mb. The months of February and March of 1980, were classified respectively as rainy and dry months. The study used the equation of water balance as applied to the atmosphere, and the divergence field for the vertically integrated water vapour flux, obtained from the finite difference method using a grid 2.5° wide. The daily radiosonde data and the monthly precipitation data for the network of such stations over the region have been used. The main conclusion is that the northeast region of Brazil acts as sink of the atmospheric humidity during the rainy months, while in the dry months, acts as a source of humidity. Although a little variation of total precipitable water has been diagnosed spatially, this aspect in itself is not sufficient to explain the observed low total precipation during the dry month.

A extensa região do nordeste do Brasil experimenta, frequentemente, secas severas, que são verdadeiramente catastroficas à região, como as ocorridas nos últimos anos de 1979 a 1983 (exceto para 1981, considerado normal). O presente estudo é um diagnóstico dos campos mensais de água precipitável, fluxo de vapor d'água e sua divergencia horizontal, integrados verticalmente entre a superfície da Terra e o nível isobárico de 300*mb.* Os meses de fevereiro e março de 1980 foram classificados, respectivamente, como chuvoso e seco. O estudo utilizou a equação de balanço da água aplicada à atmosfera, sendo o campo da divergência do fluxo obtido pelo método de diferenças finitas a partir de uma grade com *2,5°* de espaçamento. Os totais diários e mensais de precipitação, coletados durante o período pela rede pluviométrica da região foram utilizados. Como conclusão, destacamos que durante o mês chuvoso a região nordeste do Brasil atua como sumidouro de umidade da atmosfera, enquanto no mês seco comporta-se como fonte umidade. Embora se tenha diagnosticado pouca variação na distribuição espacial dos valores de água precipitável, este aspecto, por si só, não é suficiente para explicar o baixo total pluviométrico observado na região durante o mês seco.

INTRODUCTION

The important role of the atmosphere and its general circulation as a forcing factor for the water cycle has long been recognized by climatologists and hydrologists. However, the quantitative studies of the gaseous hemisphere and its aerial runoff have only been possible after the advent of an adequate network of aerological stations. The study of the various fields which characterize the flow of water vapour in the atmosphere, is necessary for improving comprehension of the global water cycle and interrelations between the terrestrial and the aerological branches.

Quantitative estimates of the total precipitable water, its vertical distribution and of the total water vapour flux and its divergence have been made for limited regions, large continental areas, hemisphere and even for the globe, for periods of a few days, months, seasons, year and decades. Notable contributions have been those by Benton & Estoque (1954). Rasmusson (1967, 1971) for North America, by Hutchings (1961) for Australia, by Peixoto & Obasi (1965) for Caribben Sea and Gulf of Mexico, by Molion (1975), for Amazon Basin and North Brazil, and by Marques (1981) and Araújo (1982) for NE Brazil. Peixoto (1972) computed pole to pole water balance for the IGY and Peixoto & Oort (1983) obtained the global distribution of the various water vapour fields for 10 year period. Howarth (1983) computed seasonal variations of water vapour transport fields over the Southern Hemisphere for 5 year period.

Considering the importance of water balance in the atmosphere, for arid and semi-arid regions, the drought prone region of NE Brazil and the typically dry year 1980 was selected for the present study. On the basis of monthly precipitation analysis and percentage departure charts, it is observed that January is a normal, February a rainy, and March to July are extremely dry months, in accordance with mean monthy precipitation charts of Strang (1972). For all these months, and for the region of NE Brazil, between 0º – 20º S and 30º – 50º W, computations have been made for total precipitation water, its vertical distribution, and for the total monthly water vapour flux and its divergence.

MATERIAL AND METHOD

In this investigation, the daily and monthly precipitation data for 153 stations, and the daily radiosonde data for 12 stations over the region have been used. The wind and specific humidity from the surface of the Earth to 300*mb* for each standart level, for each day, for each radiosonde station have been used for computation. The equations used are based on (λ, ϕ, P, t) coordinate system, where (λ) represents the longitude, (ϕ) the latitude, P the atmospheric pressure and (t) the time. In this system the total precipitable water in a unit colunm of air from the Earth's surface to 300*mb* level is given by:

$$W_P = g^{-1} \int_{300}^{P_s} q \, dP \qquad (1)$$

where g is aceleration due to gravity, q the specific humidity and P_s the pressure at the Earth's surface. The vertically integrated total water vapour flux is calculated from the expression:

$$\vec{Q} = g^{-1} \int_{300}^{P_s} q \, \vec{V} \, dP \qquad (2)$$

where $\vec{V}$ represents the horizontal wind vector, which has zonal and meridional components, u for east and v for north respectively. Thus the zonal and meridional components of the total water vapour flux are given by the expressions:

$$Q_\lambda = g^{-1} \int_{300}^{P_s} qu \, dP \qquad (3)$$

$$Q_\phi = g^{-1} \int_{300}^{P_s} qv \, dP \qquad (4)$$

The field of divergence of the vertically integrad total water vapour flux is obtained from the following expression:

$$\nabla.\vec{Q} = (a \cos \phi)^{-1} \left[\frac{\partial}{\partial \lambda} Q_\lambda + \frac{\partial}{\partial \phi} (Q_\phi \cos \phi) \right] \qquad (5)$$

where a is the radius of the Earth, λ the longitude and ϕ the latitude. The finite diferrence method with a grid spacing of 2.5^o latitude, longitude has been used for computation of the divergence. Finally, use has been made of the atmospheric water balance equation, in the following form, for assessment of the water vapour sources and sinks, in the region of NE brazil during the period of study, where **E** is the evaporation and **P** the precipitation.

$$\nabla.\vec{Q} = E - P \qquad (6)$$

THE ANALYSIS; INTERPRETATION AND RESULTS

Charts have been prepared and analysed for each of the above quantities for each month, from January to July 1980. A close examination of the monthly precipitation, and its departure charts (Figs. 1 and 2) shows that the month of February was comparatively a rainy month, and the month of March, an anomalously dry one, and rest of the months were also very dry. For economy of space, the charts of these two typical months, February and March, 1980, along with the results are presented below.

a. Precipitable water.

The vertical distribution of specific humidity (Figs. 3 and 4) shows that during the anomalously dry month of March, there is a increase of vertical gradient between the surface and 700*mb* level. During rainy month of February, the vertical gradients of specific humidity between the surface and the 700*mb* are not that strong.

The spatial distribution of total precipitable water during the rainy month of February 1980 (Fig. 5a) shows two areas with maximum values. The first one with a value

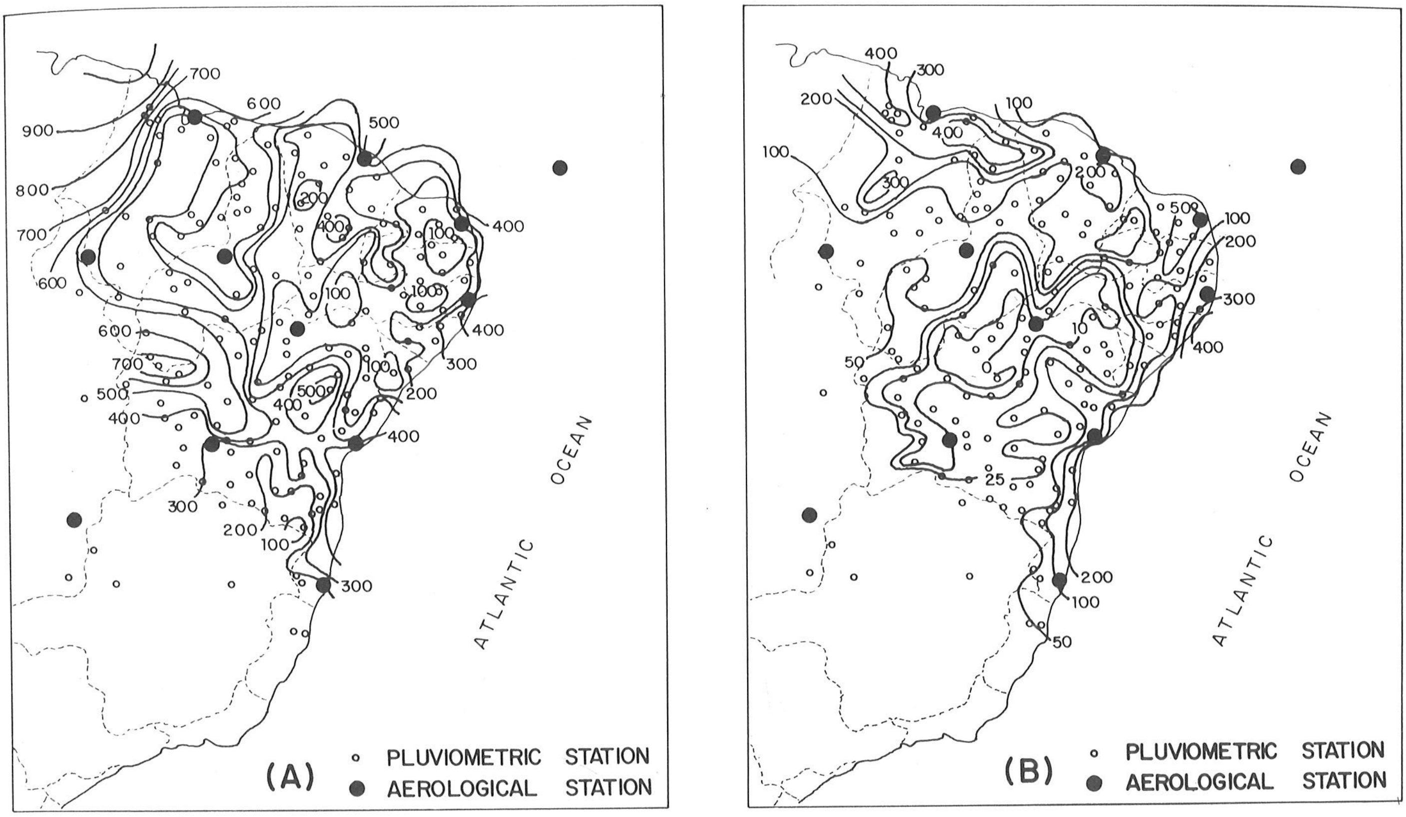

Figure 1 — Total of precipitation (*mm*). A) February and B) March of 1980.

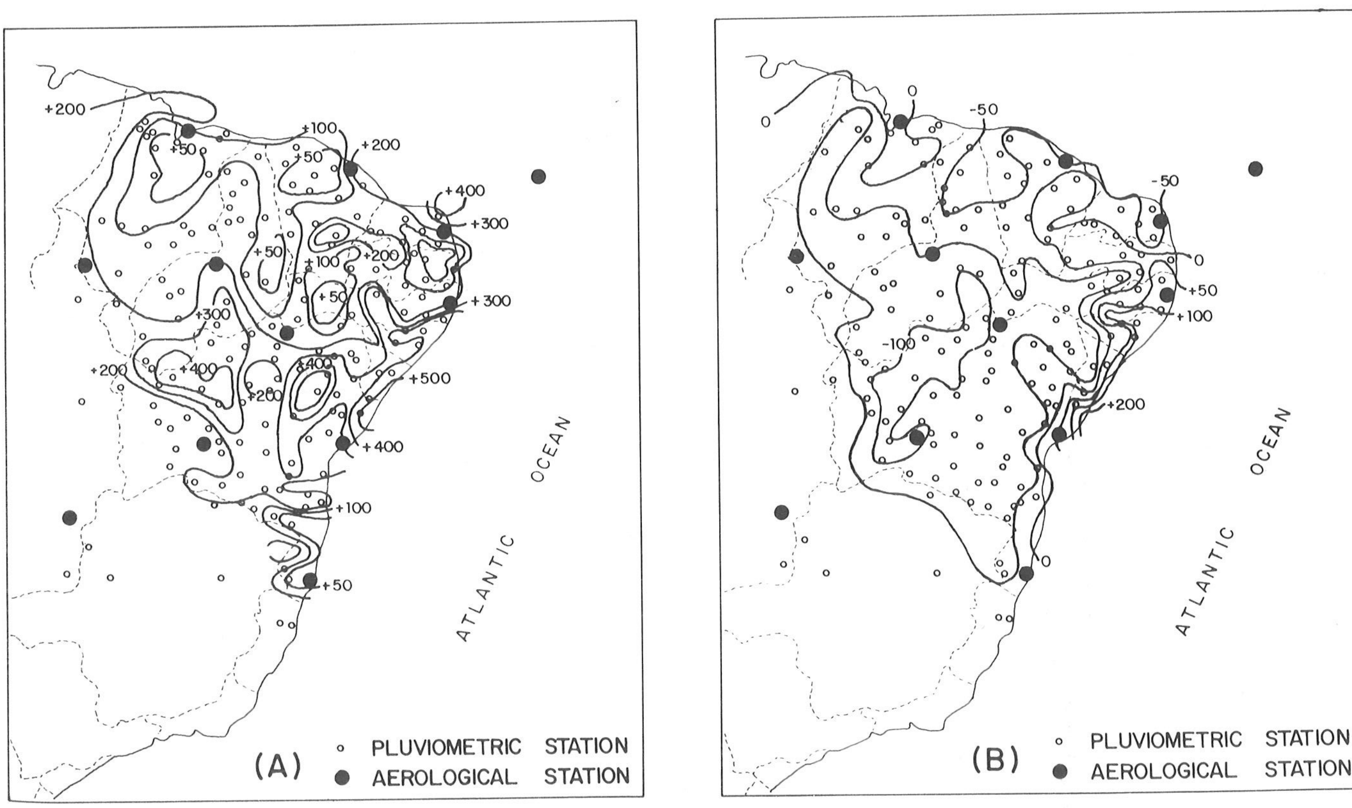

Figure 2 — Deviation of precipitation (in percentage from normal) A) February and B) March of 1980.

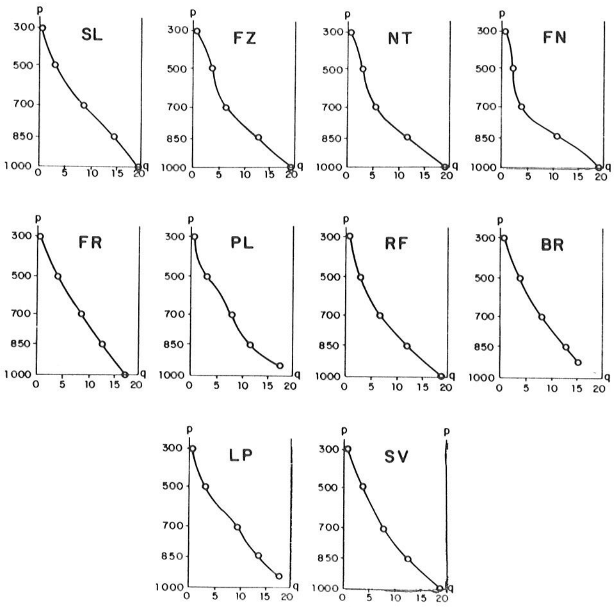

Figure 3 — Vertical distribution of specific humidity $q(g.kg^{-1})$ for each standart level P(mb), for following aerological stations: São Luiz (SL), Fortaleza (FZ), Natal (NT), Fernando de Noronha (FN), Floriano (FR), Petrolina (PL), Recife (RF), Brasília (BR), Bom Jesus da Lapa (LP) and Salvador (SV). February-1980.

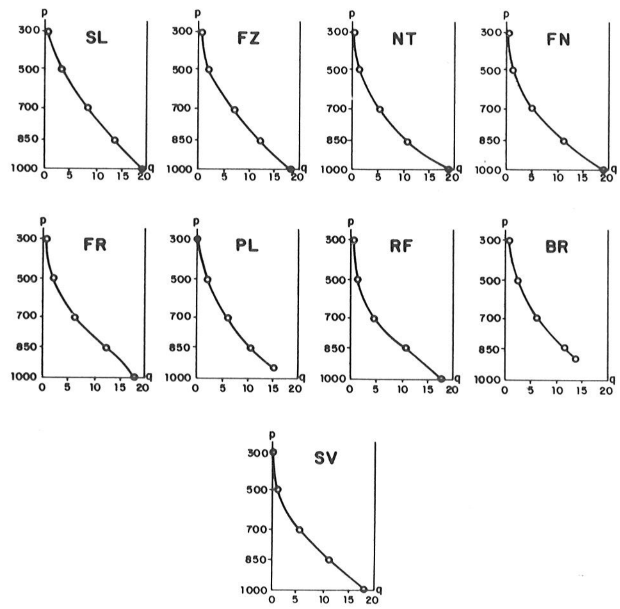

Figure 4 — Vertical distribution of specific humidity $q(g.kg^{-1})$ for each standart level (P(mb), for following aerological stations: São Luiz (SL), Fortaleza (FZ), Natal (NT), Fernando de Noronha (FN), Floriano (FR), Petrolina (PL), Recife (RF), Brasília (BR) and Salvador (SV). March — 1980.

of about 58*mm*, is located over northwest of the state of Maranhão, and another with a value of about 50*mm* is located over the coastal region of the state of Bahia. Besides this the isolines of precipitable water depict a trough like structure with its axis oriented in the northeast to southwest direction and passing over the interior of the region. Similar

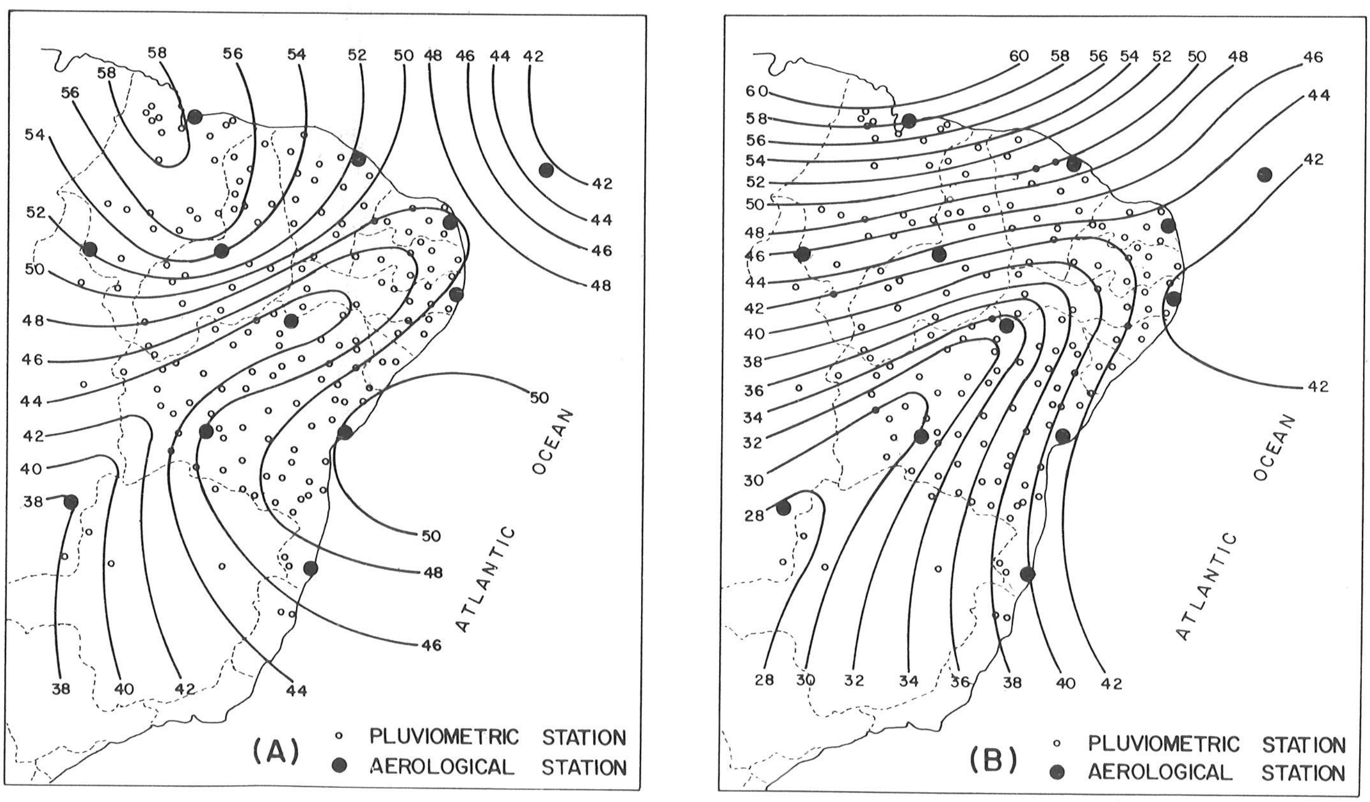

Figure 5 — Spatial distribution of total precipitable water (*mm*). A) February and B) March of 1980.

configurations have also been obtained by Araújo (1982) and Rathor et al. (1983) in their diagnostic studies. The minimum values of about 38*mm* are observed in the extreme southwest of the region i. e. over the state of south Goias. During the anomalously dry period, i. e. the month of March, 1980, the configuration of the field of total precipitable water (Fig. 5b), though similar to that of February, shows very strong north-south gradients along longitude 45ºW, and east-west gradients along latitude 15ºS. Besides this, a major part of the area of NE Brazil is enclosed by the isopleth 42*mm*, with values much lower in the interior of the region. In this configuration, a maximum value of about 60*mm* is located in the northwest and a minimum of about 28*mm* is observed over the southern part of the state of Goias.

b. The Water Vapour Fluxes, Zonal, Meridional and Total.

During the rainy month of February, the zonal flux is predominantly from the east over the major part of the area of study. During the dry month of March, the zonal flux over whole region is from the east with much more intensity than that of the rainy month. The meridional flux of water vapour during the rainy month of February is from south over the states of Ceará, Rio Grande do Norte, West Pernambuco and part of the state of Paraíba. Over the rest of the region, the meridional flux is from the north, through relatively weak. During the dry month of March, the meridional flux is predominently from the south over the whole of the region.

The configuration and intensity of the total water vapour flux during the rainy and dry periods depict markedly different features. During the rainy month (Fig. 6a), there is predominence of flow from east to west over the north coastal region. As the flux penetrates, its direction gradually turns to the south and the intensity decreases to about 1/3 of its initial value. During the dry month (Fig. 6b) the total flux is directed from east-south-east over the major part of the region, while in the southern part of the region the flow is directed from the east. It is also observed that the intensity of the total flux during the rainy month is less than that during the dry month.

c. The field of the Divergence of the Total Water Vapour flux.

The field of divergence of the total water vapour flux during the rainy month (Fig. 7a), February 1980, shows an area of significant convergence (≃ - 500*mm*) located over states of Piaui and Ceará. This area is characterized by an excess of precipitation over evaporation and is in conformity with the atmospheric water balance requirement, and strong convergence of water vapour flux is responsible for the above normal precipitation (Fig. 1a).

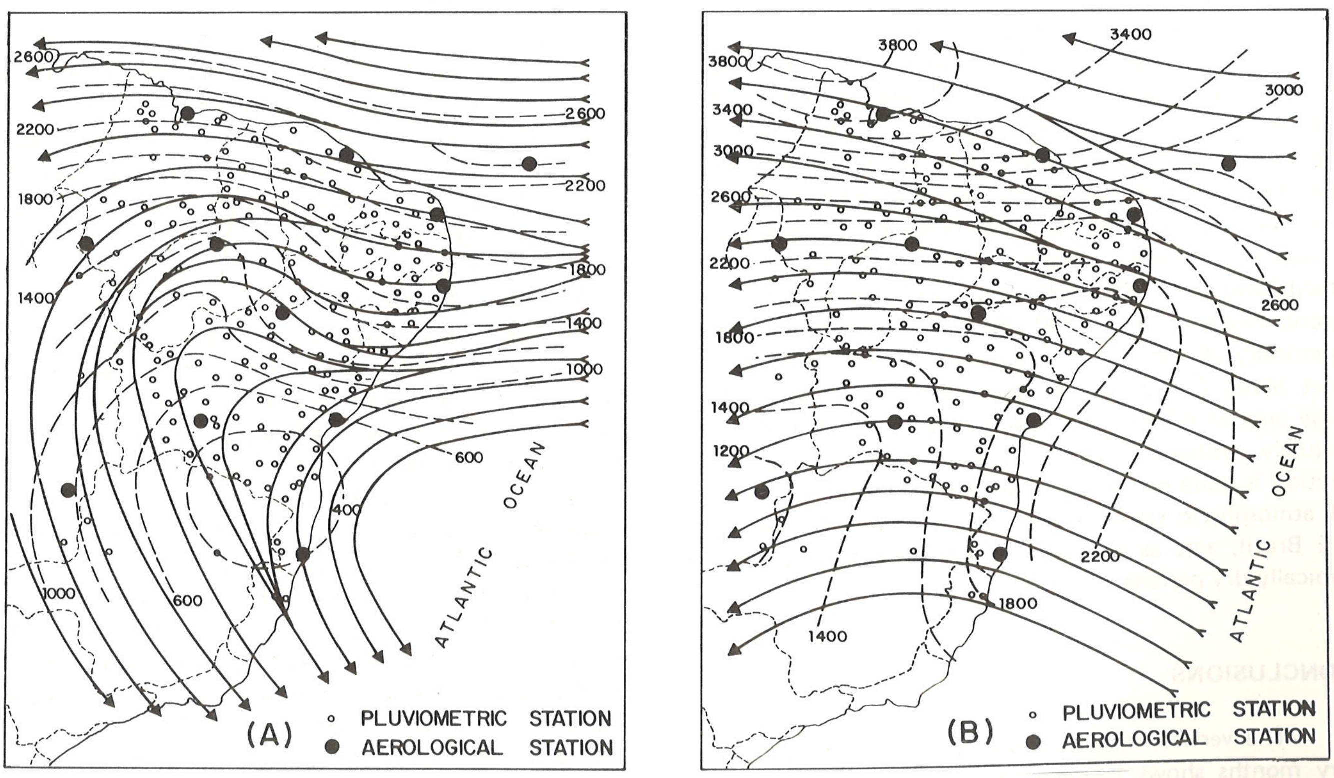

Figure 6 — Vertically integrated total water vapour flux, $g(cm.s)^{-1}$. Direction of flux shown by stream lines (full); magnitude of flux shown by intensity lines (broken). A) February and B) March of 1980.

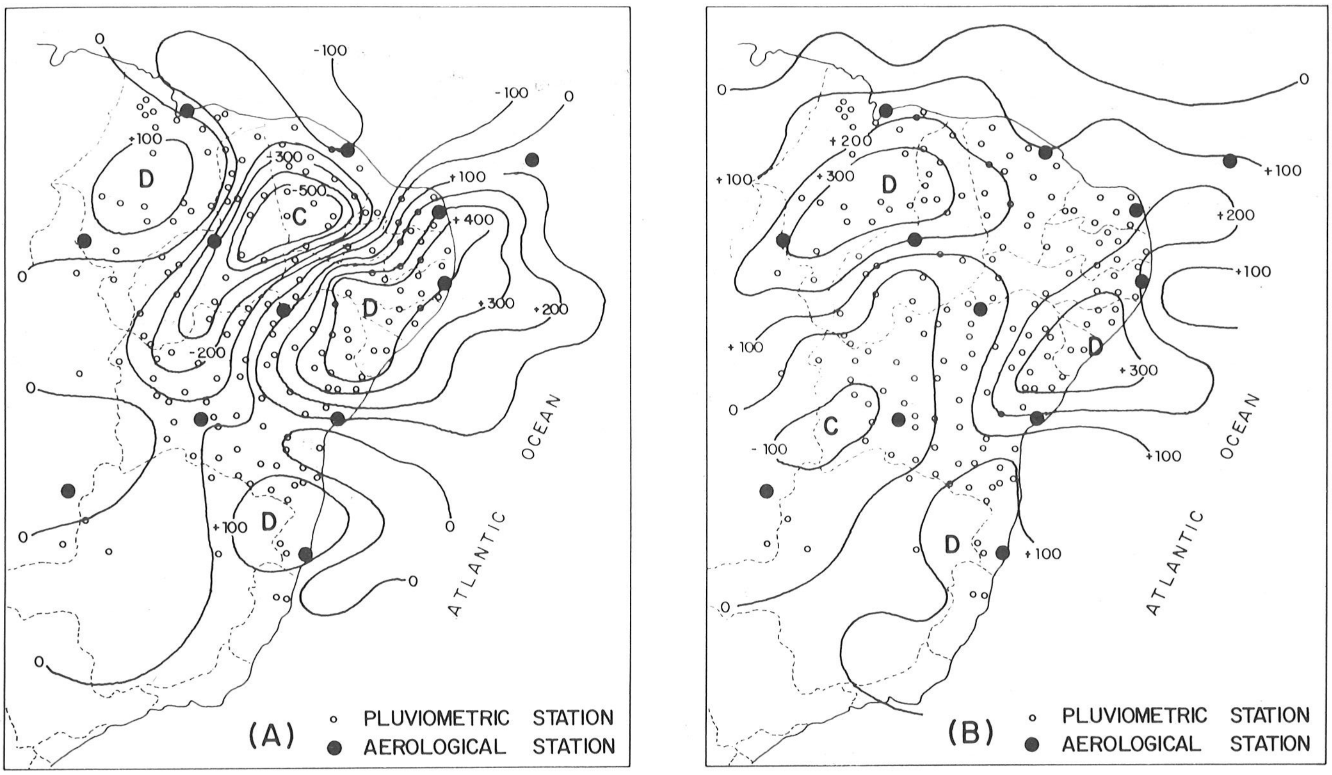

Figure 7 — Horizontal divergence field (*mm*) of the vertically integrated water vapour flux. A) February and B) March of 1980.

On the other hand, the flux divergence ($\simeq$ + 400*mm*) extends over the states of Rio Grande do Noth, Paraíba, Pernambuco, Alagoas and Sergipe. This area is associated with very scarse observed precipitation.

During the anamolously dry month of March, 1980, the divergence field of total water vapour flux (Fig. 7b) depicts an area of weak convergence ($\simeq$ - 100*mm*) over the western part of the state of Bahia and Minas Gerais and over the south part of the state of Goias. Inspite of this convergence, no precipitation occurred over the region concerned, obviously because of the very low values of precipitable water. Over the major part of NE Brazil region, strong divergence ($\simeq$ + 300*mm*) is observed, and it covers practically all the states, except part of west Bahia, northwest Minas Gerais and the adjoining part of Goias. The large area of NE Brazil, convered by strong divergence is virtually without any precipitation, and naurally evaporation is quite in excess of precipitation. Thus on account of atmospheric water balance requirement, the region of NE Brazil, acts as a source of water vapour, during the typically dry periods.

CONCLUSIONS

The vertical distribution of specific humidity during dry months shows increase of vertical gradient: between the surface and 700*mb* level, than that during the rainy months.

The isopleths of total precipitable water depict a through like configuration, with its axis oriented in the noreast to southwest direction, with lowest values in the southwest of the region. The axis of this through passes over the interior of the region with dry conditions there.

The values of total precipitable water depict a significant difference between the rainy and dry periods. The stations in the interior of the region have much lower values of total precipitable water during dry periods than those during the rainy periods.

In general, the values of the zonal and meridional components of water vapour flux are higher during the dry periods than those during the rainy periods. This is due to the intensification of the trade winds, because of the intensity and proximity of the South Atlantic high. This conclusion is in conformity with the findings of Hastenrath and Heller (1977) and Mello (1983). In the rainy months the intensity of the zonal flux decreases from east towards west and more so towards the interior southwest of the region of NE Brazil.

The field of total vertically integrated water vapour flux shows marked distinction between the rainy and dry months. During the rainy months, there is a predominance of flux from the east or east-north-east over the region of NE Brazil. This conclusion is in conformity with that of Rathor et al. (1983). During the dry months, there is a predominance of flux from east-south-east and from southeast.

In general the areas with vertically integrated total water vapour flux convergence are associated with the areas of precipitation, whereas areas with divergence are associated with little or on precipitation.

Finally, in accordance with the atmospheric water balance equation, an examination of the divergence fields shows, that in general, during the dry periods, the NE Brazil region acts as a source of water vapour for the atmosphere.

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