Large-scale circulation departures related to wet episodes in north-east Brazil

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SUMMARY

This study examines the large-scale tropical environment of north-east Brazil during its 1979 rainy season. Data were primarily from the First GARP Global Experiment (FGGE). Results show that in the mean NE Brazil is south of the intertropical trough zone (ITZ) and north-west of the South Atlantic high. This pattern results in a westward low-level flow over the region. Immediately over NE Brazil, middle-level subsidence and low-level moisture divergence dominate, producing a mean local environment which is unfavourable for precipitation. During wet episodes cloudiness departures show a more active ITZ over the equatorial Atlantic. Strong sea level pressure departures are found in the vicinity of the subtropical highs indicating short period fluctuations in the Hadley cell. Locally, weaker middle-level subsidence and weaker moisture divergence during wet episodes allow for increased convection.

1. INTRODUCTION

The drought/flood phenomenon of north-east Brazil has widespread serious socio-economic consequences. Rainfall over NE Brazil is highly variable both in space and time; however, there are distinct rainy seasons. In the north (primarily the states of Maranhao, Piaui, Ceara, Rio Grande do Norte, Paraiba, Pernambuco and Alagoa), the rainy season is centred on, but not confined to, the months of March and April and is related to the meridional position of the intertropical trough zone (ITZ) over the tropical Atlantic. Agriculture is geared for planting in December and January and harvesting in May. If droughts or floods occur in March or April, crops are ruined.

Over the past two decades, a number of studies examining various circulations associated with rainfall variability over NE Brazil have been made (Namias 1972; Hastinghath 1976; Hastinghath and Heller 1977; Kousky 1979, 1985; Moura and Shukla 1981; Chu 1983, 1984, 1985; Hastinghath 1984; Hastinghath et al. 1984; Sikdar and Elsner 1986). The concern of most of these investigations has been large-scale circulation patterns related to drought and flood years over NE Brazil. At present, knowledge of circulation patterns related to wet episodes within a particular rainy season is incomplete, mainly due to a lack of adequate observations on this time scale. This gap was narrowed during the operational phase of the First GARP Global Experiment (FGGE) in 1979. The data collected during this experiment and processed in the form of three-dimensional arrays allow for diagnosis of large-scale circulation components on a daily basis.

The object of this study is to present and discuss mean and departure fields of cloudiness, sea level pressure (s.l.p.), temperature, moisture and wind over NE Brazil and the adjacent Brazil–Atlantic sector during a particular NE Brazilian rainy season. The study divides the rainy season (March and April) into wet and dry days, then composites variables with respect to persistent rainfall episodes. Spatial fields of seasonal means and wet departures are presented.

2. DATA SOURCE AND ANALYSIS TECHNIQUES

Sea level pressure, temperature, moisture and wind grid point values along with satellite-based cloud amount estimates constitute the main data base. The grid point data were obtained from the European Centre for Medium-range Weather Forecasts
(ECMWF) and cloud amounts were estimated from GOES-east infrared imagery from the National Climatic Data Center (NCDC) in Asheville. Monthly rainfall totals for stations in NE Brazil were obtained from Monthly Climatic Data for the World. Daily totals were received from both NCDC and from the Superintendencia do Desenvolvimento do Nordeste (SUDENE) in Recife, Pernambuco, Brazil.

Cloud amounts are estimated in 5° latitude–longitude areas from infrared full disc pictures. Estimates are made three times daily, at 00, 12 and 18 GMT for March and April. Occasionally the 00 or the 12 GMT picture is missing, in which case the 06 GMT picture is substituted. The estimating procedure excludes cloudiness which appears dull grey to the eye. The possible effect of this low brightness cutoff is to exclude cloud regions consisting primarily of stratus or small cumulus. Cloud amounts are then averaged to obtain daily means.

Daily means of the other variables are calculated from the 00 and 12 GMT grid point data. Spatial fields of daily mean upper air variables at 20, 50 and 85 kPa along with s.l.p.s are analysed over an area from 30°N to 30°S and 60°W to 15°E. A detailed discussion of the four-dimensional data assimilation scheme used at ECMWF to produce the grid point data is given by Lorenc (1981). Pearce and Mohanty (1984) note the work of Kanamitsu (1980) who inferred from climatological comparisons that the level-IIIb data produced at ECMWF were suitable for diagnostic studies.

Vertical motions were not taken directly from the level-IIIb package but rather were estimated kinematically (O'Brien 1970) from the vertically integrated divergence after forcing zero divergence at 10 kPa.

Initially the rainy season is divided into wet and dry days using daily rainfall totals for stations in NE Brazil. The ten stations are uniformly distributed over the region (Fig. 1). Table 1 gives the station name, coordinates, elevation and WMO number. Averaging criteria are based on the following. A day is marked as wet if it meets either of the following two conditions: (1) more than two stations over the region with recorded precipitation; (2) less than three stations with precipitation, but total rainfall exceeding 10 mm. As a further condition, in order to isolate rainfalls associated with pronounced

Figure 1. Base map of study area. Isohyets of total rainfall over NE Brazil for March and April 1979 are shown. The dry region is roughly delineated by the 200 mm isohyet. The ten rainfall stations are also indicated.
TABLE 1. RAINFALL STATIONS

<table>
<thead>
<tr>
<th>Name</th>
<th>Lat. (S)</th>
<th>Long. (W)</th>
<th>Elev. (m)</th>
<th>WMO No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quixeramobin</td>
<td>04°48'</td>
<td>39°33'</td>
<td>250</td>
<td>82786</td>
</tr>
<tr>
<td>Crato</td>
<td>07°02'</td>
<td>39°29'</td>
<td>450</td>
<td>82784</td>
</tr>
<tr>
<td>Floriano</td>
<td>06°52'</td>
<td>42°52'</td>
<td>150</td>
<td>82678</td>
</tr>
<tr>
<td>Petrolina</td>
<td>08°25'</td>
<td>40°47'</td>
<td>500</td>
<td>82983</td>
</tr>
<tr>
<td>Paulo Alfonso</td>
<td>09°35'</td>
<td>38°13'</td>
<td>300</td>
<td>82986</td>
</tr>
<tr>
<td>Irecê</td>
<td>10°54'</td>
<td>41°35'</td>
<td>450</td>
<td>83182</td>
</tr>
<tr>
<td>Teresina</td>
<td>05°03'</td>
<td>42°48'</td>
<td>70</td>
<td>82578</td>
</tr>
<tr>
<td>Bom Jesus</td>
<td>08°46'</td>
<td>44°24'</td>
<td>390</td>
<td>82975</td>
</tr>
<tr>
<td>Campina Grande</td>
<td>07°19'</td>
<td>36°01'</td>
<td>470</td>
<td>82795</td>
</tr>
<tr>
<td>Crateus</td>
<td>04°56'</td>
<td>40°45'</td>
<td>290</td>
<td>82583</td>
</tr>
</tbody>
</table>

weather systems, only days within a precipitation event lasting three days or longer are used in the averaging. All departure fields are based on these criteria. Figure 2 is a histogram plot of the normalized rainfall departures, with wet episodes identified.

TABLE 2. TEN-STATION MEAN MONTHLY PERCENTAGE OF TOTAL YEARLY PRECIPITATION

<table>
<thead>
<tr>
<th>Month</th>
<th>Mean</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>19-0</td>
<td>12-1</td>
</tr>
<tr>
<td>February</td>
<td>13-5</td>
<td>9-6</td>
</tr>
<tr>
<td>March</td>
<td>14-5</td>
<td>7-0</td>
</tr>
<tr>
<td>April</td>
<td>13-2</td>
<td>6-2</td>
</tr>
<tr>
<td>May</td>
<td>11-2</td>
<td>10-3</td>
</tr>
<tr>
<td>June</td>
<td>4-0</td>
<td>5-2</td>
</tr>
<tr>
<td>July</td>
<td>3-3</td>
<td>6-3</td>
</tr>
<tr>
<td>August</td>
<td>2-8</td>
<td>7-6</td>
</tr>
<tr>
<td>September</td>
<td>0-8</td>
<td>1-3</td>
</tr>
<tr>
<td>October</td>
<td>0-7</td>
<td>1-8</td>
</tr>
<tr>
<td>November</td>
<td>7-1</td>
<td>5-6</td>
</tr>
<tr>
<td>December</td>
<td>9-6</td>
<td>9-6</td>
</tr>
</tbody>
</table>

As a way to put the rainfall during March and April into seasonal perspective, Table 2 shows the ten-station mean monthly percentages of total yearly rainfall for 1979 along with standard deviations. January through May have the largest mean percentages,

![Normalized Rainfall Departures](image)

Figure 2. Normalized rainfall departures. Wet episodes are indicated with a bar below the graph.
with March and April of these five months having the smallest variations. This indicates that as a whole March and April had relatively good spatial coverage of rainfall.

For an interannual perspective, the only two stations with 30-year climatological records indicated negative departures for March and April of 1979.

Means and departures of all fields are smoothed using a 25-point normal smoothing filter. Results are presented in section 3 and summarized in section 4.

3. Results

(a) Seasonal means

In this subsection we present seasonal mean fields. Upper, middle and low levels refer to 20, 50 and 85 kPa surfaces respectively. Percentage ‘bright-cloud’ amounts are shown in Fig. 3. Minimum cloudiness (less than 30%) associated with the subtropical high pressures is found north of 5°N and south of the equator. Maximum cloudiness is located over the Amazon basin and between the equator and 5°N over the tropical Atlantic associated with the ITZ. The mean s.l.p. field is shown in Fig. 4. Clearly depicted are the subtropical high pressure regions and the ITZ. The mean field is in good agreement with the 61-year means for March and April (Hastenrath and Lamb 1977). The cloudiness and s.l.p. fields also show good agreement and we note that the ITZ is north of NE Brazil.

The mean low-level mixing ratio field is shown in Fig. 5. Highest mixing ratios are found over central Brazil and along the coast of west central Africa. Values of mixing ratio over NE Brazil are relatively high compared with values over the adjacent South Atlantic.

Mean upper-level winds (Fig. 6(a)) are generally westerly with highest speeds near 30°N. Over much of Brazil, including the north-east, winds are light southerly and south-westerly. At low levels (Fig. 6(b)), winds over the Atlantic circulate round the subtropical highs of both hemispheres resulting in westward flow over the eastern half of Brazil. This mean low-level flow carries dry South Atlantic air over NE Brazil. Relatively strong winds are noted along the north coast of NE Brazil.

![Figure 3. Mean percentage of bright-cloud field. Note maximum cloudiness band north of the equator.](image)
Figure 4. Mean s.l.p. (mb) field. Note the equatorial extensions of the subtropical highs.

Figure 5. Mean 85 kPa mixing ratio (g kg⁻¹) field. Highest mixing ratios extend along the equator and over the Amazon basin.

The mean upper-level velocity divergence field (not shown) indicates a band of convergence extending from the eastern South Atlantic to NE Brazil. Over much of the remainder of Brazil we find divergence. At low levels divergence is situated over NE Brazil with an adjacent centre of convergence to the south-east over central Brazil. The low-level moisture divergence field (Fig. 7) is similar to the velocity divergence field. A centre of relatively strong moisture divergence is located immediately over NE Brazil.

As can be expected from the divergence fields, middle-level subsidence (see Fig. 8) is noted over all NE Brazil. Mean subsidence over NE Brazil during the rainy season
Figure 6. Mean (a) 20 kPa and (b) 85 kPa wind vector fields. Wind speeds are proportional to vector length. Note low-level onshore winds over NE Brazil.

has been noted by Sikdar and Elsner (1986). Rising motion is found over the remainder of Brazil. A zonal band of rising motion associated with the ITZ is located along the equator extending from north of NE Brazil to the west coast of Africa.

The mean upper-level vorticity field (not shown) indicates anticyclonic flow over much of the tropics. A notable exception is along the coast of southern Brazil where a region of cyclonic vorticity is found. This vorticity along the coast may be associated with mid-latitude troughs (Kousky 1985).

From the above analyses, it is apparent that the mean environment over NE Brazil
Figure 7. Mean 85 kPa moisture divergence (10^{-5} s^{-1}) field.

Figure 8. Mean 50 kPa kinematically derived vertical velocity (10^{-2} m s^{-1}) field. Note subsidence over NE Brazil.

during the rainy season of 1979 was unfavourable for precipitation mainly due to low-level moisture divergence and regional middle-level subsidence.

(b) Departure fields

Departure fields presented in this subsection are generated as the difference between seasonal mean and wet episode composite fields. Departure patterns of bright-cloud amounts are shown in Fig. 9. Positive departures over NE Brazil are expected since
cumulus convection is the primary precipitation mechanism of the region (Ramos 1975). Over the equatorial Atlantic positive departures indicate a more active ITZ during wet episodes. Negative departures are confined to a portion of the eastern North Atlantic.

Sea level pressure departures are presented in Fig. 10. Relatively strong negative departures are noted over the western South Atlantic extending over NE Brazil, with positive departures over portions of the North Atlantic. The departures are a result of longitudinal shifts or intensity changes of the subtropical high pressure centres.
Figure 11. Meridional profile of s.l.p. (mb) departures zonally averaged from 15 to 60°W. Largest departures are noted south of 15°S.

Figure 11 shows the meridional profile of s.l.p. departures zonally averaged from 15°W to 60°W. Largest departures are noted south of 15°S. The signs of the departure values over the Atlantic are similar to those detected on the annual cycle (Hastenrath et al. 1984). However, in contrast to studies of interannual variability such as Chu (1983), we find no latitudinal displacement of the ITZ.

Positive departure of mixing ratio are found centred over NE Brazil (Fig. 12). Pearce and Mohanty (1984) note that moisture is the poorest of the FGGE products and we find on the whole that the departure field of mixing ratio is noisy. Caution is therefore necessary when discussing the significance of specific departure regions.

Wind departures are presented in Figs. 13(a, b). At upper levels anomalous southerlies are located over NE Brazil. The southerlies are on the eastern side of a broad region

Figure 12. Wet episode departure field of 85 kPa mixing ratios in g kg⁻¹. Note positive departures over NE Brazil.
of cyclonic circulation extending from central Brazil north-eastward to the eastern North Atlantic. Strongest departures are noted with this circulation, particularly over the ocean. At low levels anomalous north-westerlies are found over NE Brazil. These anomalous winds are a result of weaker easterlies during wet episodes. Figure 14 shows the meridional profile of low-level zonal wind speed departures zonally averaged from 15°W to 60°W. Positive departures south of the equator indicate weaker easterlies. A slackening of the low-level easterlies during wet periods has been mentioned by Kousky (1985). Further, Chu (1983) has noted weak easterlies at low levels during wet years. Wind departures are generally small over the remainder of the field except near 30°N.

Figure 13. Wet episode departure fields of (a) 20 kPa and (b) 85 kPa wind vectors. Note low-level anomalous off-shore flow over NE Brazil.
Figure 14. Meridional profile of 85 kPa zonal wind speed departures zonally averaged from 15 to 60°W. Positive departures south of the equator indicate weaker easterlies compared with the mean.

At upper levels velocity convergence (not shown) is stronger than the mean over NE Brazil, however, over the remainder of Brazil positive departures indicate stronger divergence. A region of positive departure is found off the north-east coast of NE Brazil. The departure field at low levels is weak. Over NE Brazil, negative departures are a result of weaker than normal divergence during wet episodes. Low-level moisture divergence departures are displayed in Fig. 15. Negative departures over Brazil indicate either a weakening of moisture divergence (NE Brazil) or a strengthening of moisture convergence (south-central Brazil) during wet episodes. Strongest departures are found to the south of NE Brazil. Over this same region we find relatively strong negative vertical

Figure 15. Wet episode departure field of 85 kPa moisture divergence (10^{-5} s^{-1}). Note a large region of negative departure over NE Brazil.
velocity departures at middle levels (Fig. 16) indicating stronger upward motion during wet episodes.

At the upper level, vorticity departures (not shown) indicate negative anomalies over NE Brazil suggesting stronger cyclonic rotation over this region. Positive departures revealing generally an increase in anticyclonic rotation are noted over central Brazil.

Departure fields of s.l.p., wind and moisture for wet episodes show a large-scale environment which is less hostile towards precipitation.

4. Summary and Conclusions

We have performed an analysis of atmospheric circulation components over NE Brazil and the adjacent tropical Atlantic for March and April of 1979 using data accumulated during FGGE and processed by ECMWF in the form of twelve-hourly grid point values. Seasonal mean and departure fields based on rainfall episodes over NE Brazil were computed for various circulation components.

Results show that during its rainy season, NE Brazil is south of the ITZ. The ITZ is clearly indicated in both cloud and moisture fields. Further, the South Atlantic subtropical high pressure region is centred to the south-east of NE Brazil in the mean. This high results in a low-level dry air flow from the east over NE Brazil. Also, large-scale mean middle-level subsidence is found over portions of the equatorial South Atlantic extending over NE Brazil. Therefore, it is noted that the large-scale environment over NE Brazil is unfavourable for rain.

Wet episodes were then identified and departure fields generated as the difference between the mean and composite fields. Departure fields of wet episodes indicate changes in the large-scale environment which are considerably more favourable for precipitation than is the mean state. A more active ITZ is noted in the cloudiness field. Low-level easterlies (indicated by anomalous westerlies) are weaker over NE Brazil and portions of the South Atlantic. This helps in producing weaker moisture divergence across NE
Brazil. Weaker easterlies are a result of lower pressures over a large portion of the western South Atlantic. Concurrently, s.l.p.s over much of the North Atlantic are higher than the mean. Sea level pressure departures over the subtropics on this time scale may indicate short-term fluctuations of the Hadley cell. Middle level subsidence over NE Brazil is also weaker during wet episodes.

This study provided an analysis of the large-scale environment for a single NE Brazilian rainy season. We expect to make further studies in attempts to understand circulation changes associated with day-to-day weather over NE Brazil particularly in the light of the increased availability of remote sensing information.

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