Atmospheric Circulation Changes Associated with Rainfall Anomalies over Tropical Brazil*

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ABSTRACT

During February–March 1981, striking contrasts existed in the rainfall distribution over most of Brazil and in the atmospheric circulation features over South America and the North and South Atlantic Oceans. Drier than normal conditions prevailed during February in the eastern and northeastern sections of Brazil. This was followed by an excessively wet March. The onset of the rainfall was associated with a low level equatorward propagating convergence zone that originated as a cold front at higher latitudes in the Southern Hemisphere. During the period of strong convection, when observed rainfall rates in many areas exceeded 20 mm d⁻¹, a strong anticyclonic circulation developed in the upper troposphere over the eastern Atlantic and west-southwest of the maximum rainfall rates. Another anticyclonic center developed north of the equator forming a couplet which is strikingly similar to the theoretical upper level flow pattern associated with a tropical heat source. The Northern Hemisphere midlatitude circulation changes over the Atlantic are quite similar to those associated with the recently studied 30–60 day oscillation, and to the North Atlantic Oscillation.

1. Introduction

The region of Northeast Brazil has received considerable attention from researchers due to its large interannual rainfall variability. Early studies (e.g., Mossman, 1919; Walker, 1928) linked this variability to meteorological events at distant locations within the tropics and subtropics of both hemispheres. Namias (1963) showed that tropical rainfall variations over the Americas are, at times, related to middle and high latitude atmospheric circulation changes in the Northern Hemisphere during the northern winter and spring months. Namias (1972), extending his earlier work, showed that wetter than normal conditions over Ceará, Northeast Brazil are positively correlated with lower than normal 700 mb geopotential heights over the North Atlantic in the region of Newfoundland. North Atlantic ridging, on the other hand, is associated with drier than normal conditions over Northeast Brazil. Hastenrath and Heller (1977) demonstrated that on a seasonal basis the intensities of the northeast and southeast trades are related to rainfall variations in Northeast Brazil. They determined that the Intertropical Trough Zone (ITZ) is north of its normal position when the northeast trades are weaker and the southeast trades are stronger than normal. Under these condi-

tions, northern Northeast Brazil experiences drier than normal conditions. As pointed out by Moura and Shukla (1981), the latitudinal position of the ITZ is probably not the only factor involved in causing interannual rainfall variations since the differences in the position of the ITZ, obtained by Hastenrath and Heller between the composites for ten extremely wet years and for ten extremely dry years, are quite small.

By using daily data, some of the weather producing systems have been studied for the region of Northeast Brazil. The influence of Southern Hemisphere cold fronts on rainfall has been studied by Kousky (1979). Upper tropospheric cold lows and their effects on cloudiness in eastern Brazil have been investigated by Kousky and Gan (1981). Each of these systems organizes convective cloudiness on the synoptic scale. Another factor that is important in daily rainfall variations is the interaction between local wind circulation regimes and the synoptic-scale flow pattern. The importance of the local wind systems in producing diurnal rainfall variations over Northeast Brazil has been treated by Kousky (1980). The rainy season in Northeast Brazil is rather short, extending from February to May with rainfall rarely being uniformly distributed. Instead, as noted by Ramos (1975) in his description of the 1972 rainy season, a relatively small number of precipitation events, sometimes only a few days in length, are separated by longer intervals of no rain.

In this paper we focus on the extremely wet and dry periods which characterize the 1981 rainy season. The differences in the atmospheric circulation pattern dur-
ing these periods will aid in understanding the causes for the extremes and may well provide important information on the circulation patterns associated with extreme interannual variations.

2. Data and analysis procedures

The tropospheric circulation data presented here were derived from the National Meteorological Center's twice-daily tropical grid final analysis. A comprehensive description of this type of analysis can be found in Arkin (1982). The data were obtained on magnetic tape from the National Center for Atmospheric Research. The 850 and 250 mb mean circulation patterns were analyzed manually for the periods 11–20, 21–28 February, 1–10, 11–20, 21–31 March and 1–10 April 1981. These periods were chosen to facilitate comparison of circulation features with observed total rainfall data, which are available from the Boletim de Agroclimatologia published by the Brazilian National Institute of Meteorology. Daily rainfall data for Northeast Brazil

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**Fig. 1.** Rainfall totals for (a) 21–28 February, (b) 1–10 March, (c) 11–20 March and (d) 21–31 March 1981. Isoline interval is 100 mm with the dashed line indicating 50 mm. Circles indicate stations having rainfall data for the period. Solid circles indicate no rainfall measured during the period. Areas having greater than 100 mm are shaded.
were obtained from the Superintendência do Desenvolvimento do Nordeste (SUDENE), Recife, Brazil.

3. Description of circulation and precipitation changes

During the first week of March, a series of cold fronts enhanced convective activity over southeastern and central Brazil, resulting in a substantial increase in rainfall during 1–10 March from that observed during 21–28 February (compare Fig. 1a and b). The convective activity gradually spread northeasterly and increased in strength during 11–20 March (Fig. 1c) and continued strong through 21–31 March (Fig. 1d). During the last three weeks of March rainfall totals at many stations in the normally semiarid interior of Northeast Brazil were nearly equivalent to the normal annual totals.

The northeasterly displacement of the rainfall activity is evident in the time series of average daily rainfall constructed for selected regions of Northeast Brazil. The station locations within each of the four regions chosen are shown in Fig. 2. In the southernmost region (Region 4) rainfall increased beginning 8 March, while in the remaining regions the onset of rainfall was delayed until 11–12 March (Fig. 3). All of the time series show marked contrast between the very dry period of February and early March and the very wet period during the last three weeks of March. Also evident in

Fig. 2. Locations of stations used in constructing the time series shown in Fig. 3. Individual stations are indicated by dots. Regions in Fig. 3 are indicated by encircled numbers.

Fig. 3. Average daily rainfall (mm) for the stations within each of the four regions shown in Fig. 2.
FIG. 4. Mean streamline and isotach patterns at 850 mb (left portion) and 250 mb (right portion) for the periods (a and b) 11–20 February, (c and d) 21–28 February and (e and f) 1–10 March 1981. Isotach interval is 5 m s⁻¹.
the more northern time series (Regions 1 and 2) is a very abrupt start in the rainfall activity with rainfall reaching a peak during 20–25 March followed by a gradual decline in activity through the first part of April.

Marked changes occurred in the atmospheric circulation pattern over South America and the South Atlantic between February and March 1981. Upper tropospheric ridging in the western Atlantic near 40°S during February (Figs. 4b and 4d) gave way to troughing by early March (Fig. 4f). Associated with the upper tropospheric troughing, the 850 mb anticyclone over the South Atlantic was displaced southeastward (com-
pale Figs. 4a and 4e). As a consequence, the southeasterly trades over eastern and northeastern Brazil weakened and disappeared altogether by mid-March 1981 (Fig. 5a) when the low-level flow became northerly or northwesterly. These changes in the atmospheric circulation pattern accompanied the equatorward advance of southern cold fronts which had been essentially "blocked" during February.

Large tropospheric circulation changes also occurred during February–March 1981 in the North Atlantic. During mid-February, strong ridging was present over the central North Atlantic with very weak 250 mb flow between 30 and 40°N and a strong subtropical jet (STJ) extending from the eastern Caribbean east–northeastward across North Africa (Fig. 4b). By 11–20 March (Fig. 5b), this pattern was replaced by a strong jet near 30°N extending from the southeastern United States eastward into the central Atlantic. The flow over North Africa became weak. The North Atlantic 850 mb circulation pattern changed dramatically from anticyclonic in mid-February (Fig. 4a) to cyclonic flow beginning in late February (Fig. 4c) continuing until late March (Fig. 5c). By 1–10 April many features of the 850 and 250 mb circulation patterns resembled those that existed in mid-February (compare Figs. 4b and 5f and Figs. 4a and 5e).

4. Discussion and conclusion

Most circulation features and related rainfall anomalies associated with the intraseasonal variations discussed above agree with features describing interannual variations (see the Introduction). The dry period (February) was characterized by ridging in the North Atlantic, which as shown by Namias (1972) is related to drier than normal conditions in northern Northeast Brazil. The wet period (March) showed a pattern of strong cyclonic activity in the North Atlantic, again agreeing with the results of Namias (1972). The changes in the circulation of the 850 mb subtropical highs in both the North and South Atlantic Oceans are consistent with the results obtained by Hastenrath and Heller (1977) for extreme rainfall departures over northern Northeast Brazil. However, as pointed out by Moura and Shukla (1981), the ITZ may not be the only factor involved in producing the observed rainfall anomalies in Northeast Brazil. Indeed, during March 1981 the weakened southeasterly trades over Northeast Brazil contributed to a weaker ITZ with less convergence than normal. This is evident in the pattern of outgoing longwave radiation (OLR) (Fig. 6) for 16–31 March 1981 which shows high values of OLR in the central equatorial Atlantic.

The appearance of northerly low-level winds over Northeast Brazil is another feature observed during very wet periods (Markham and McLaren, 1977). Apparently, the equatorward advance of a midlatitude southern cold frontal system, similar to those described by Kousky (1979), lowers the surface pressure over eastern Brazil and allows for the weakening of the trades and appearance of northerly winds. Also, the convergence zone associated with southern cold fronts is instrumental in initiating and organizing intense convective activity over Brazil.

Looking more closely at the regional circulation changes over South America, one notes that there is an anticyclonic couplet present at 250 mb during the period of greatest convective activity (see Fig. 5b). The anticyclone located near 15°S, 65°W is situated to the west–southwest of the region of greatest rainfall amounts, and the overall pattern appears to be quite similar to that obtained by Gill (1980) for a stationary tropical heat source, and by Silva Dias et al. (1983) for a transient tropical heat source. The anticyclonic couplet to the west of the heat source (rainfall maximum) and strong near-equatorial westerlies to the east of the

**Fig. 6.** Outgoing longwave radiation 16–31 March 1981. Data are accumulated and averaged over 2.5° areas and interpolated to a 5° Mercator grid for display. Contour interval 20 W m\(^{-2}\). Contours of 280 W m\(^{-2}\) and above are dashed.
heat source bear remarkable resemblance not only to the results of the above studies but also to the upper tropospheric anomaly pattern associated with warm sea surface temperatures in the equatorial central Pacific (Arkin et al., 1983).

The large-scale changes in the upper tropospheric circulation pattern over the North Atlantic described above are consistent with those associated with the North Atlantic Oscillation (Wallace and Gutzler, 1981) and with the 30–60 day oscillation recently described by Weickmann (1983) and Weickmann et al. (1985). Weickmann (personal communication, 1985) confirms that the November 1980–March 1981 period was characterized by a particularly strong 30–60 day oscillation with persistent subtropical ridging over the Atlantic in January and early February giving way to a strong and southward-shifted North American jet in late February and March. As shown by Weickmann, the 30–60 day oscillation is most evident during northern winter in the atmospheric circulation of the Northern Hemisphere and in the outgoing longwave radiation (OLR) anomalies within the tropics. The OLR anomalies are greatest over the Indian Ocean extending eastward to the central Pacific, but are also quite large over eastern and northeastern Brazil. The northward propagation of a negative OLR anomaly over eastern Brazil is evident in Fig. 12 of Weickmann (1983) and is consistent with our results showing the convective activity increasing first in the south and then gradually moving northward with time. Our results suggest that the 30–60 day oscillations may be characterized by substantial Southern Hemisphere midlatitude circulation changes. Further work is necessary to adequately document these changes and their relationship to shifts in tropical convective activity.

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REFERENCES


