Influence of northern hemisphere general circulation on drought in northeast Brazil[1]

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ABSTRACT

Evidence is presented to show that the highly variable interannual rainfall over Northeast Brazil is dependent on the degree of cyclonic activity or blocking in the Newfoundland–Greenland area during the Northern Hemisphere winter and spring. The linkage is traced through variations in the subtropical Atlantic anticyclone, the northeast trades and the responding Hadley cell which is forced to vary in position and strength. Intense blocking over North America and the North Atlantic is usually associated with devastating drought over Northeast Brazil.

Introduction

Precipitation over many parts of Northeast Brazil is highly variable from year to year—occasionally there is severe drought. This variability and its associated economic impact have been largely responsible for a UNDP-WMO program to improve the observational network and learn more about the meteorology of the area (Bernard & Wurtele, 1971).

The precipitation is also highly variable in space as shown by a chart of the mean annual rainfall (Fig. 1). We shall not attempt to discuss this complex rainfall pattern but refer the reader to standard literature on the climate of Brazil (Kendrew, 1961). Our purpose will be to explore some of the time-dependent rainfall variations, well illustrated in Fig. 2 by the three-month totals for December through February and March through May observed from 1947 through 1970 at Quixeramobim, a station with a long homogeneous record. Quixeramobim's location is shown by the heavy solid circle in Fig. 1. These large seasonal variations are superimposed on an annual course of rainfall which has its maximum in spring of the Northern Hemisphere—Table 1 lists the climatological averages by month. It will be noted that precipitation increases fourfold from January to April—from 43 to 160 mm. Mean sea level pressure charts for these months (Naval Weather Service

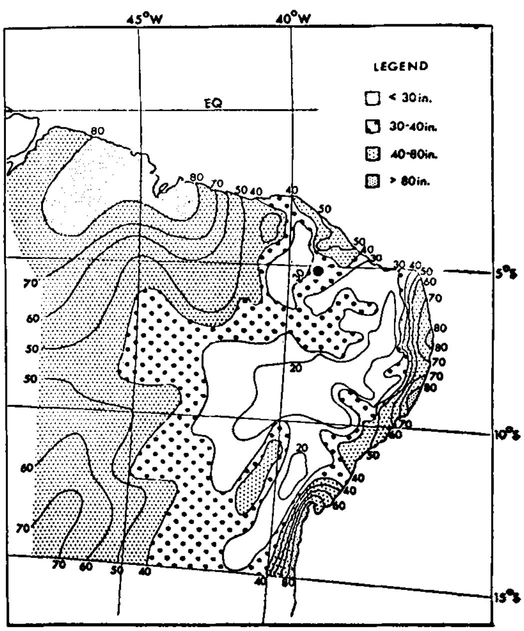

Fig. 1. Mean annual rainfall (inches) for Northeastern Brazil (from Bernard & Wurtele, 1971). Heavy solid circle locates Quixeramobim.

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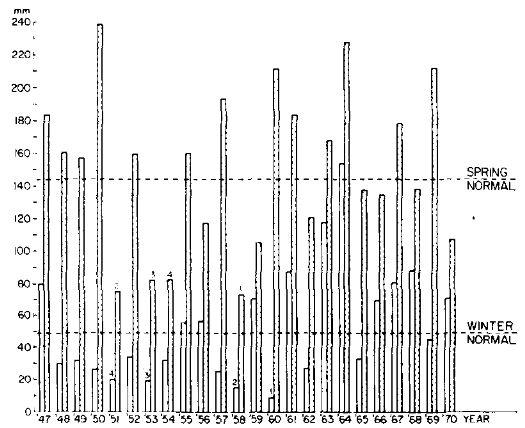


Fig. 2. December through February (open bars) and March through May rainfalls (hatched bars) at Quixeramobim, Brazil (5°12′ S 39°18′ W). Top of bar represents total rainfall for a three-month period, e.g., in the period December 1946 through February 1947, 80 mm fell while from March to May 1947, 184 mm fell. Normals (broken lines) are climate averages for Northern Hemisphere winter and spring seasons. Numbers show the four driest December–February and March–May periods.

Table 1. *Monthly precipitation (in mm) for Quixeramobim, Brazil (W 5°12′ S 39°18′) (from U.S. Dept. of Commerce, 1966)*

	Precipitation (mm)
January	43
February	88
March	171
April	160
May	102
June	39
July	20
August	9
September	4
October	3
November	6
December	16
Total	661

Command, 1969, not reproduced) show little difference in the pressure pattern affecting this area. Charts of resultant gradient winds and isotachs (Atkinson & Sadler, 1970), like that for January reproduced in Fig. 3, show that the intertropical convergence zone (ITCZ) lies about 10 degrees of latitude north of Quixeramobim n January and a few degrees farther south than this in April. Table 2 shows that surface and 700 mb temperatures as well as lapse rates in this layer in the vicinity of Quixeramobim have little difference between January and April. The largest differences between these two months appear in the dew points at surface and 700 mb, and, as stated previously, the precipitation totals. Some of the increased moisture indicated by the higher April dew points may result from the increased precipitation, particularly from high convective clouds superimposed on large-scale vertical motions, while

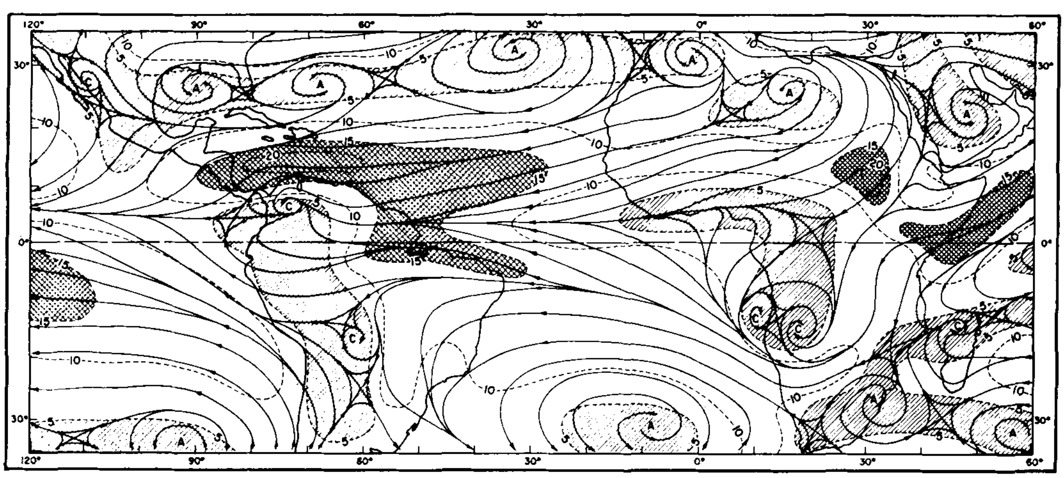


Fig. 3. Resultant gradient-level wind and isotachs for January (from Atkinson & Sadler, 1970).

some of it may be advected inland from the ocean by monsoonally increased southeast trade winds.

Returning to the question of seasonal rainfall variations around the climatological mean we find that the standard deviation of December–February precipitation is 35 mm with a long term mean of 49 mm while comparative figures for the March–May period are 48 mm and 144 mm respectively. The four driest December–February periods of the 1947–1970 period are indicated in ascending order in Fig. 2 by numbers as are the four driest March–May periods. It will be noted that three of the four very dry December–February periods were followed by very dry March–May periods, the exception being 1960 when a very wet three months followed a very dry December–February. Note that all four of the driest March–May periods were preceded by dry December—February periods. The above described sequences suggest that drought periods (very deficient rains in the wet season) are associated with anomalous meteorological patterns which have appreciable longevity. In this respect drought in Northeast Brazil, in the heart of the tropics, is similar to drought over the central plains of the United States (Namias, 1960).

Some idea of the impact in terms of human suffering is indicated by the fact that in the year of most severe drought (1958) an estimated 10 000 000 people were forced to emigrate from Northeast Brazil (Bernard & Wurtele, 1971).

I shall attempt to show that extensive dry periods in Northeast Brazil such as those indicated in Fig. 2 are associated with large-scale features of the general circulation over northern hemisphere areas more than 5 000 miles away. This idea stems from an earlier work (Namias, 1963) in which it was shown that a strong subtropical high and poleward displacement of the upper level westerlies over eastern North America and the Atlantic was associated with bands of above and below normal precipitation in Central and South America. When the reverse situation occurs (weak subtropical high with equatorward displacement of the westerlies) the precipitation bands also reverse; areas which were above normal in rainfall during periods of strong subtropical anticyclones go to below normal when the anticyclone is weak or absent, and vice versa. The difference in the geographical location of the heavy and light precipitation bands was attributed to variation in the intensity and position of the Hadley cell through its poleward limb in the subtropical high.

Table 2. *Temperatures (°C) at surface, 700 mb; temperature difference (ΔT) between surface and 700 mb, dew point (DP) at surface and 700 mb at 5° S 40° W (near Quixeramobim, Brazil) and precipitation at Quixeramobim (from U.S. Dept. of Commerce, 1966)*

$T_{surface}$	T_{700}	ΔT	$DP_{surface}$	DP_{700}	Precip. (mm)
January					
28.5	9.5	19.0	19.5	0	16
April					
27.3	8.9	18.4	22.0	3.6	160

Quixeramobim's precipitation might reflect the vigor and position of the Hadley cell which in turn would be associated with the strength of the trade winds emanating from the subtropical Atlantic High (see Fig. 3). Thus strong northeast trades would enhance rising motion in the ITCZ and possibly displace the ITCZ farther south. Once strengthened, the rising motions and attendant increase in latent heat release would impose demands on the *southeast* trades. The strengthened southeast trades would then provide a greater influx of moist air from the South Atlantic into Northeast Brazil. These effects, the greater vigor of the Hadley cell, its closer proximity to Quixeramobim and the increased moisture flux from the Atlantic would result in increased precipitation at Quixeramobim. Conversely, weakened northeast trades emanating from a weak subtropical high, would produce a weak Hadley cell, the ITCZ in a more northerly position and less demand on the southern trade wind system. The net result would be deficient rainfall at Quixeramobim.

In order to test this hypothesis Quixeramobim's December–February and March–May precipitation for 24 available years of record were correlated with contemporaneous 700 mb heights over the North Atlantic and eastern North America. The resulting isopleths of correlation are shown in Fig. 4. These fields show maxima near or off Newfoundland in

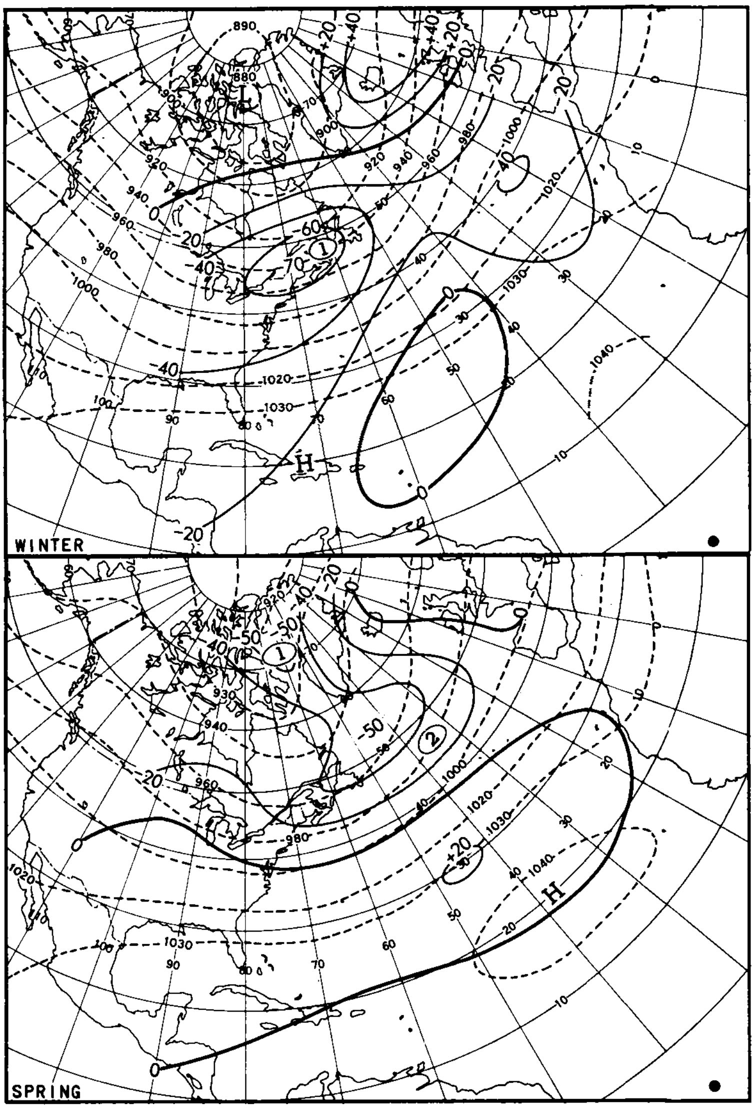


Fig. 4. Isopleths (solid) of correlation between Quixeramobim seasonal precipitation and 700 mb height elsewhere for Northern Hemisphere winter (Dec., Jan., Feb.) and Spring (Mar., Apr , May). Broken lines are normal seasonal 700 mb height contours. Solid circle at lower right of figure shows approximate location of Quixeramobim.

both Northern Hemisphere winter and spring. Note that these maximum values are *negative*, indicating that low 700 mb heights (strong cyclonic activity) in that area are associated with heavier precipitation at Quixeramobim, while high 700 mb heights (blocking) go with deficient precipitation. In the area of the subtropical anticyclones, however, the correlations, while positive, are insignificant. At first glance, this would appear to negate or at least not support the hypothesis advanced above. However, long range forecasting experience indicates that a strong teleconnection exists between 700 mb heights over the Newfoundland–Greenland area and the Atlantic High; strong cyclones in the Newfoundland–Greenland area go with strong subtropical highs, while anticyclones (blocking) go with

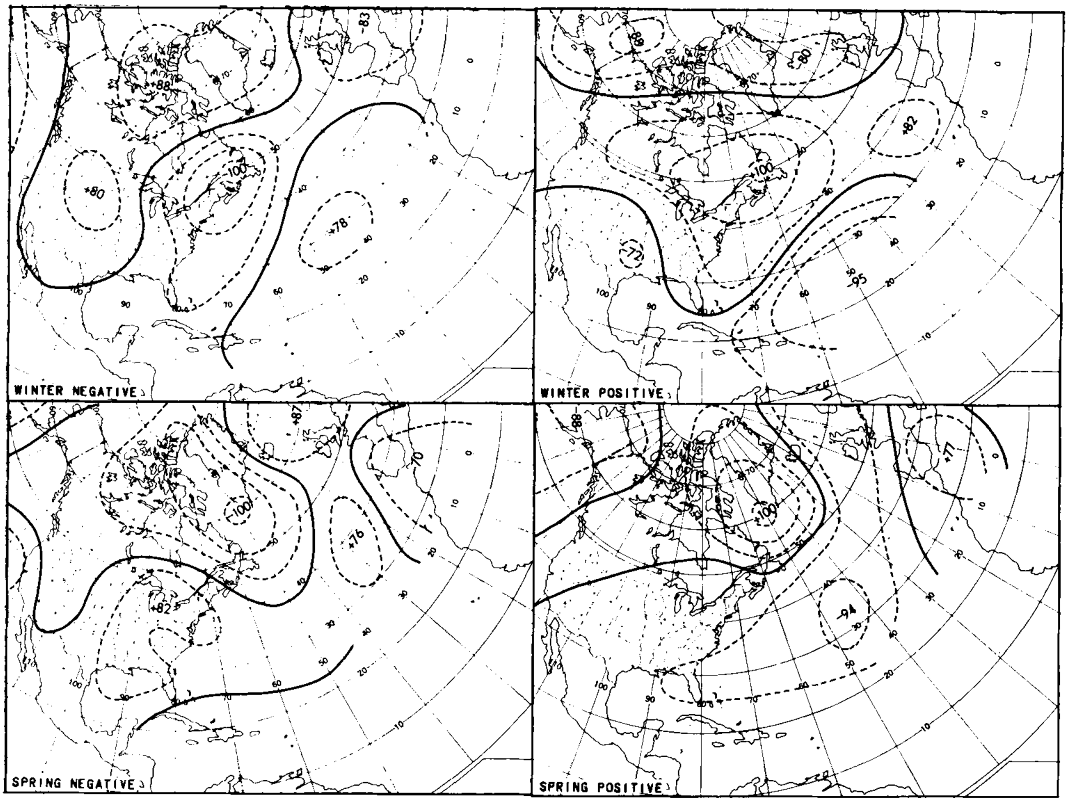
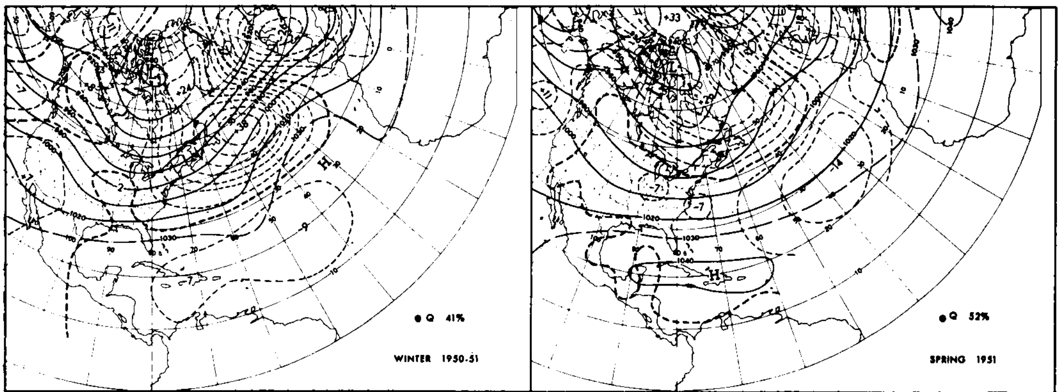


Fig. 5. Isopleths giving the probability of sign of anomaly of 700 mb height when a center of maximum anomaly dominates the area indicated by the figure 100. Other numbers give centers of maximum (positive or negative) probabilities. Isopleths are drawn for four probability contours—50 %, 70 %, 90 % and 100 %. The 50 % line is heavy solid, others are broken.

weak or absent subtropical highs. This casts doubt on some of the lower latitude correlations shown in Fig. 4. On further investigation, these turned out to have been computed from an inhomogeneous record of observed 700 mb heights. From 1947 to 1962 hand analyses had been made using continuity and synoptic expertise. Since 1962 the heights have been obtained by *numerical* (computerized) analyses—analyses which are recognized as reliable for middle latitudes but unfortunately not for southern latitudes because of sparseness of data and complex boundary effects.[1]

[1] The relative deterioration of the subtropical 700 mb data in the period since 1962 is indicated by the fact that the spring correlations between heights at 60° N 50° W (off Greenland) and at 30° N 35° W are -0.69 for the period 1947–61 but $+0.11$ for the period 1962–71.

To be more objective, I made use of the teleconnections for areas off Newfoundland and Greenland (areas of maximum correlation shown in Fig. 4) as determined by O'Connor (1969) from 17 years of 5-day mean 700 mb charts ending in 1963—essentially before the advent of computerized analysis. These teleconnections have been found to characterize monthly and seasonal as well as 5-day patterns. The charts (Fig. 5) show the probability of sign of 700 mb anomaly when a negative or positive center lies in the area marked 100. Hence, in winter, negative centers (deep troughs) in the Newfoundland area have a high probability of being associated with strong Atlantic anticyclones, while positive areas (blocking) are associated with weak or frequently absent Atlantic anticyclones. In spring similar teleconnections are found when the key



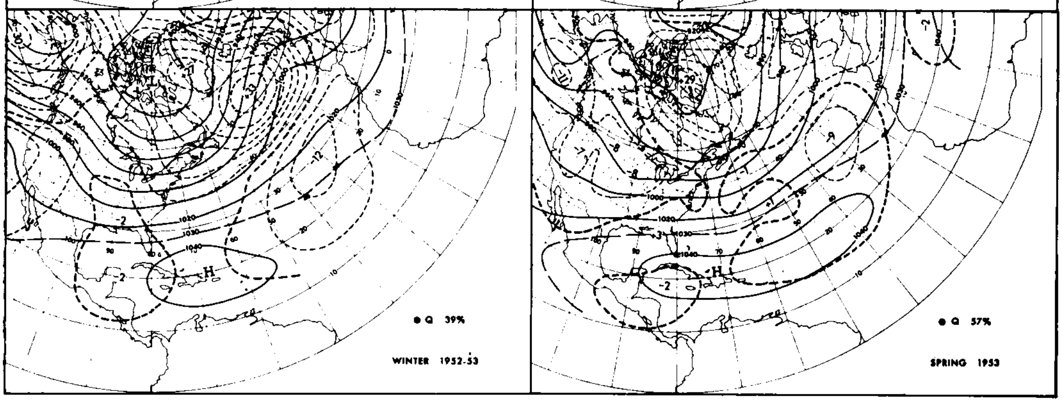


Fig. 6. Isopleths of 700 mb height (solid) and departure from normal (broken) for winter 1950–51 and spring 1951. Numbers at centers of isopleths of anomaly give maximum departures in tens of feet. Contours are labelled in tens of feet. Approximate location of Quixeramobim is given at lower right of figure along with per cent of normal of its seasonal precipitation.

Fig. 7. Same as Fig. 6 but for winter 1952–53 and spring 1953.

center appears off Southern Greenland—the area suggested by the maximum correlation centers of Fig. 4.

The charts shown in Figs. 4 and 5 lend considerable support to the hypothesis discussed earlier—namely that the northeast trades are often regulated by the Atlantic subtropical anticyclone which is in turn regulated by the upstream westerly, long-wave activity—particularly the intensity of the trough near Newfoundland. These variations alter the intensity of convergence into the ITCZ and perhaps change its position, so that variable demands may be placed on the southeast trade wind system affecting the moisture influx to Northeast Brazil from the South Atlantic. The net effect of these regional changes in Northeast Brazil is to enhance or suppress precipitation and produce large year to year variations, such as those shown in Fig. 2.

Winter and spring 700 mb patterns and their variations from normal for the drought years 1951, 1953, 1954 and 1958 (Fig. 2) are reproduced in Figs. 6 to 9. Note that in all cases strong blocking (positive height anomalies) was present near Newfoundland or off Greenland and the Atlantic anticyclone was weak or absent (negative anomalies). It is during the seasons of Northern Hemisphere winter and spring that we might expect to find relationships between Northern Hemisphere pressure patterns and Equatorial or Southern Hemisphere precipitation. This is because the vigor of the general circulation in the Northern Hemisphere is greatest during this half-year and its large-amplitude, long waves become a major feature of the global circulation. Since this is the half-year when Quixeramobim gets most of its rain, it is perhaps not surprising that drought in this area can be related

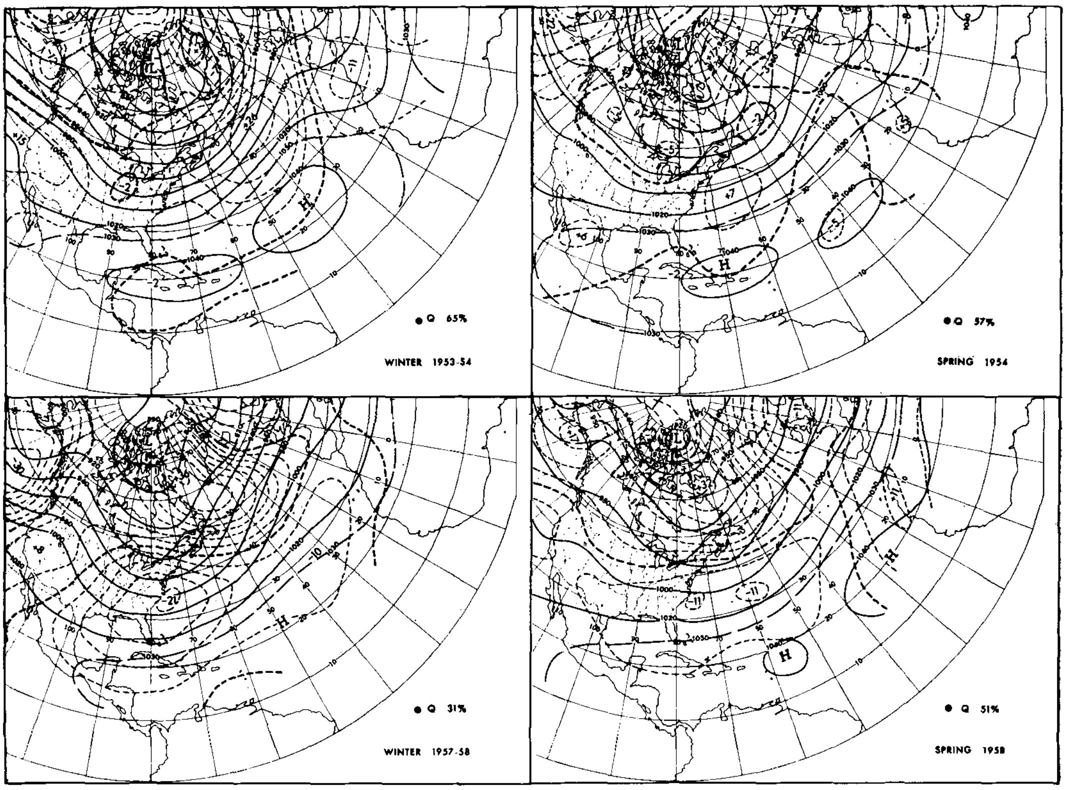


Fig. 8. Same as Fig. 6 but for winter 1953–54 and spring 1954.
Fig. 9. Same as Fig. 6 but for winter 1957–58 and spring 1958.

to Northern Hemisphere patterns. By reversing this argument it is conceivable that summer and fall precipitation in parts of the Northern Hemisphere, especially at low latitudes, might be influenced by the general circulation of the Southern Hemisphere. Increased data in the Southern Hemisphere associated with the World Weather Watch program of WMO and research carried on by GARP should throw light in this problem in the next decade.

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ВЛИЯНИЕ ОБЩЕЙ ЦИРКУЛЯЦИИ В СЕВЕРНОМ ПОЛУШАРИИ НА ЗАСУХИ В СЕВЕРО-ВОСТОЧНОЙ БРАЗИЛИИ

Представлены доказательства, что большая межгодичная изменчивость осадков над северо-восточной Бразилией зависит от степени циклонической активности и блокирования в районе Нью-Фаундленд–Гренландия зимой и весной для северного полушария. Связь прослеживается через изменения субтропического антициклона в Атлантике, северо-восточные пассаты и связанную с ними ячейку Хадлея, которая изменяет свое положение и интенсивность. Интенсивное блокирование над Северной Америкой и Северной Атлантикой обычно сопровождается опустошительными засухами в северо-восточной Бразилии.