INTERACTIONS OF CIRCULATION AND WEATHER BETWEEN HEMISPHERES

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ABSTRACT

Strongly opposing circulations for two extreme winter months over the Northern Hemisphere are associated with latitudinal bands of opposing temperature and precipitation anomalies extending through North, Central, and South America. These distributions may be produced by regional variations in the position of the Hadley cell associated with strong planetary wave displacements in temperate latitudes.

Around the turn of the century a number of investigators tried to find evidence for connections between weather phenomena in different parts of the world by use of statistical methods, mainly correlation. Among the best known work of this kind was that of Sir Gilbert Walker [12] and H. H. Clayton [2], both of whom indicated "teleconnections" not only between remote stations in the Northern Hemisphere but between places in the two hemispheres as well. Walker's "Southern Oscillation" was established upon such material, and in recent years his work has been pursued by Berlage [1] and Schell [6].

While the correlation approach frequently brings to light intriguingly high values, occasionally between points in the two hemispheres, it is difficult to explain the cross-connections and, indeed, even to be sure of the statistical significance of the correlations. As the coverage of meteorological data over the world increases and hopefully reaches the stage recommended in the report detailing the "World Weather Watch" [13], in which Dr. Harry Wexler played a major role, meteorologists may reinstitute the search for interactions with the help of synoptic as well as statistical tools, thereby providing more concrete evidence to assist in the formulation of physical theories. Precisely this route led to the discovery and theory of the Rossby [5] planetary waves as Northern Hemisphere data expanded in scope and quantity.

The purpose of this brief report is to suggest the existence of certain interrelationships between the prevailing or average monthly weather characteristics of North, Central, and South America through synoptic analysis of extreme cases. The fundamental idea was an *a priori* concept that certain relationships are probable and discoverable when the general circulation affecting North America is highly abnormal during northern winter. At this time abnormality is frequently produced by great meanders in the time-averaged planetary waves of the

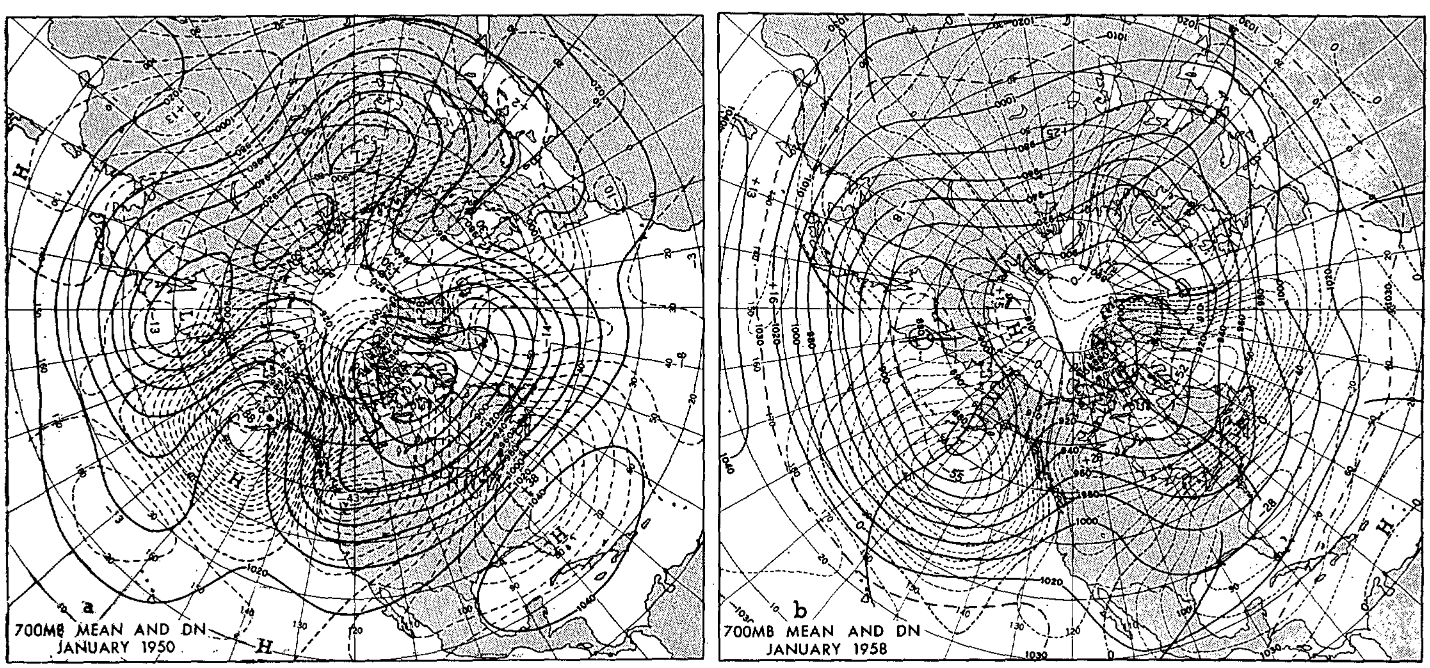

FIGURE 1.—Mean monthly 700-mb. heights, labeled in tens of feet and drawn for every 200 ft., and departures from normal with centers in tens of feet and drawn for every 50 ft. (a) January 1950 and (b) January 1958.

westerlies and their associated jet streams. The vigor of this gross austausch might logically be expected to influence the northeast trades, the Hadley cell, and, through a complex chain of events, perhaps much of South America.

Two strongly abnormal and contrasting regimes of circulation, those for January 1950 and January 1958, were selected for study from the past 15 years during which data were reasonably reliable. They are illustrated by the mean 700-mb. patterns shown in figures 1a and 1b. The opposition in phase of the wave train over North America and the adjacent oceans is highlighted by the superimposed height anomaly fields. In 1950 the westerlies were displaced equatorward in western United States and poleward in the east, while in 1958 the reverse was true.

Unfortunately, no adequate data exist for the construction of similar upper-air charts for South America and the adjacent oceans. An attempt to construct maps for sea level using the climatic reports [7, 8] has, however, been made and is shown in figures 2a and 2b. From these figures it is at once clear that over South America the differences in *sea level pressure* between the two Januaries are small (it was summer there) and that these differences in many areas might lie within the limits of observational error. On the other hand, the differences over the Northern Hemisphere are large, and the anomalies are quite similar to those at 700 mb. The sea level pressure differences between January 1950 and January 1958 in the Northern Hemisphere are portrayed in figure 3. Some idea of the strength of the Bermuda High in January 1950 and its weakness in January 1958 is gained by comparing the ±7-mb. anomalies at 30° N., 70° W. with the standard deviation of 3 mb. at this point derived from a series of January maps for the 62-yr. period 1899–1960. (Unpublished material furnished by H. C. Willett of the Massachusetts Institute of Technology in connection with the M.I.T.–U.S. Weather Bureau Extended Forecasting Project.)

Although we cannot detect any outstanding differences between the two Januaries in the South American sea level pressure distributions, are there real differences which may come to light in other elements like temperature and precipitation? The question arises because of the well-known large variations in tropical and summer rainfall, in areas of both hemispheres, which are not easily related to sea level pressure, but are related to the vertical-motion field, moisture, and stability. The latter three

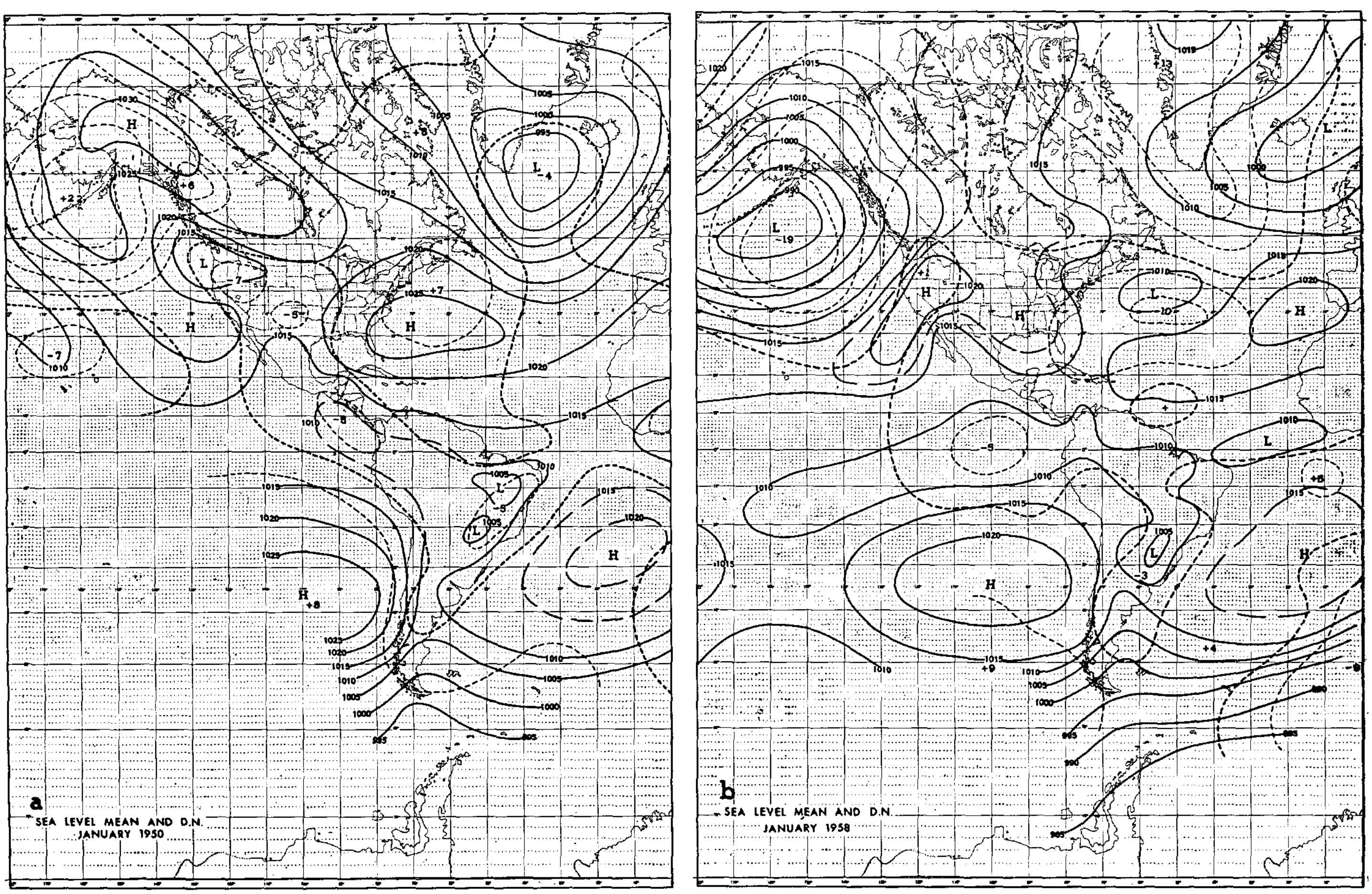

FIGURE 2.—Mean monthly sea level pressure, labeled in mb. and drawn for every 5 mb., and departures from normal with centers in mb. and drawn for every 5 mb. (a) January 1950 and (b) January 1958.

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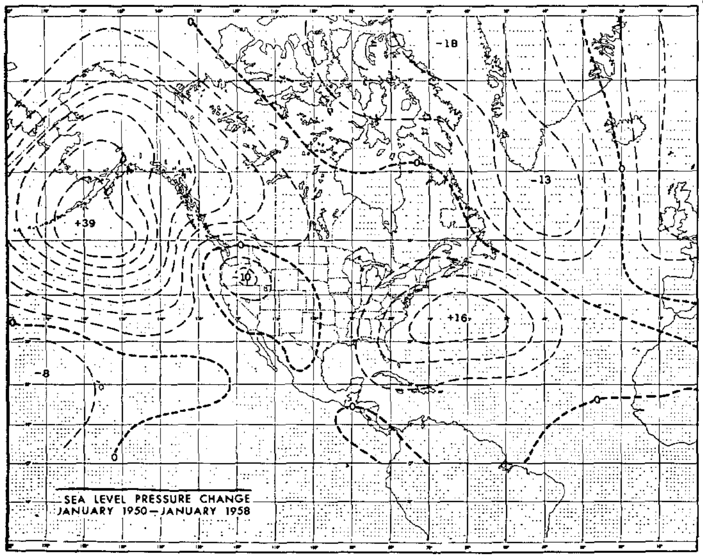

FIGURE 3.—Change in mean monthly sea level pressure, January 1950 minus January 1958, Northern Hemisphere only. Centers labeled in mb. and drawn for every 5 mb.

parameters are quite possibly related to the upper-wind fields, which in turn may be affected by anomalous events to the north. For example, subsidence is known to occur well south of the jet stream at tropopause level.

The percentage of normal January precipitation for each of the Januaries is plotted in figures 4a and 4b, where each isopleth is drawn for doubled values after the ±25 percent line. The pattern for the United States has been copied from the U.S. Weather Bureau *Weekly Weather and Crop Bulletin.* The values elsewhere have been obtained using data extracted from the climatic reports mentioned above and from *World Weather Records* [9, 10, 11].

We shall now point out some salient features of the precipitation charts, particularly as they relate to the pressure and height fields (figs. 1 and 2). In January of 1950 (fig. 4a) [1] the heavy precipitation over much of the eastern United States owed its origin to convergence and vertical ascent of moist tropical air associated with the strong southerly flow of air brought about by the strong Bermuda High. Of course, the principal mechanisms for creating the ascent of air are cyclones generated between cold air inducted by the western upper-level trough and the mild eastern air. Farther south, roughly between latitudes 15° N. and 30° N., appreciably subnormal rainfall was observed and is related to the anomalously strong upper-level ridge which may be seen (fig. 1a) to extend from the western Atlantic through the Gulf of Mexico. The ridge indicates the relative absence of frontal systems and cyclone waves, and the domination of anticyclones with prevalent subsidence. In northern portions of South America another band of appreciably heavier than normal rainfall occurred, apparently associated

[1] Further description of the synoptic events of the month is given by Klein [4].

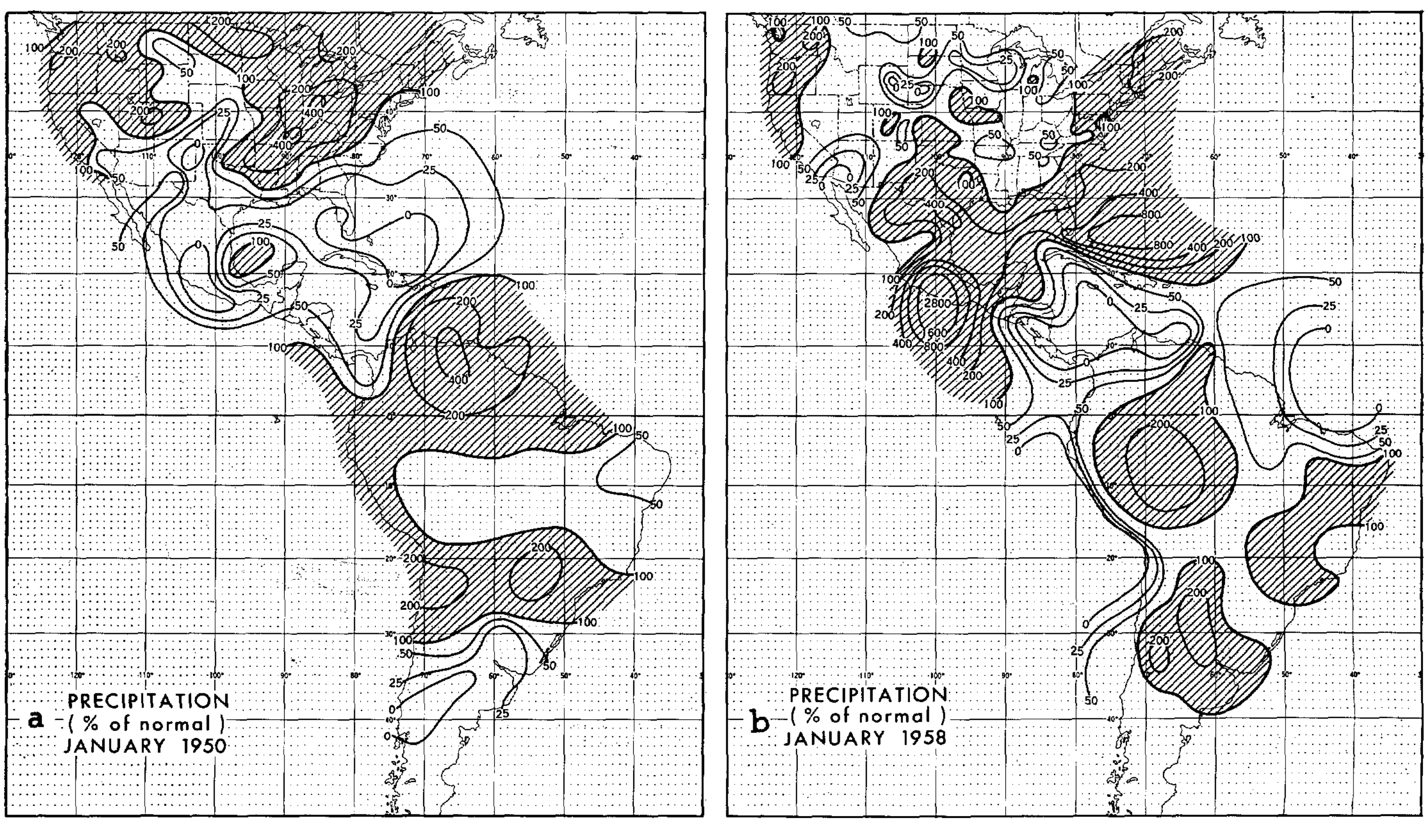

FIGURE 4.—Percent of normal precipitation. Isopleths drawn for 0 and 25 percent, and for doubled values thereafter. Greater than 100 percent shaded. (a) January 1950 and (b) January 1958.

with enhanced easterly wave activity as suggested by the anomalously strong upper-level anticyclone to the north. Still farther south we find a series of alternating latitude zones of above and below normal precipitation about 10° wide, perhaps created in response to the unusually large northward displacement of the equatorial rain band (the upward branch of the Hadley cell).

For January 1958, both circulation and rainfall patterns are out of phase with those of January 1950. The strong upper-level trough over eastern United States was associated with strong outbreaks of Polar air, as may be seen from the mean sea level pressure distribution in figure 2b, and the Polar Front was displaced far southward in the Gulf of Mexico and Mexico. The cyclonic activity along the Polar Front not only resulted in the anomalously heavy rains from Florida westward through the Gulf, but also in one of the heaviest total rainfall amounts observed at Acapulco, Mexico (140 mm. compared with a normal of 5 mm.). It should be stressed that these rains were *not* produced by tropical systems in the usual sense, but by Polar Front disturbances generated in an area where Polar air is rarely found and where the adjacent warm water masses provide a vast moisture reservoir. South of the Polar Front and upper-level westerlies, in this case around 10° N., we find a characteristically dry zone, while at about 10° S., 20° S., and 30° S. we again find suggestions of banded and alternating rainfall patterns, although not as clearly as in January 1950. A close inspection of figures 4a and 4b will reveal that the relatively dry areas on one chart are in general replaced by moist ones on the other, and vice versa. This opposition is shown in figure 5, where interpolations from the isopleths along latitudes have been averaged for both Januaries. The apparent effects of the great southward displacement of the westerlies of January 1958 relative to January 1950 can be followed through Central and South America, as indicated by arrows and letters.

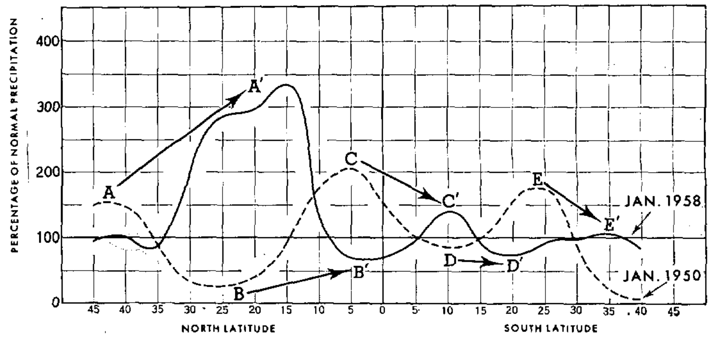

FIGURE 5.—Latitudinal profile of rainfall, derived from figure 4 and expressed as percentage of normal precipitation. Solid curve, January 1958; dashed, January 1950. Arrows with letters indicate probable shifts in ascending and descending branches of meridional cells.

We may also see opposition between 1950 and 1958, as well as banded structure, in the fields of temperature

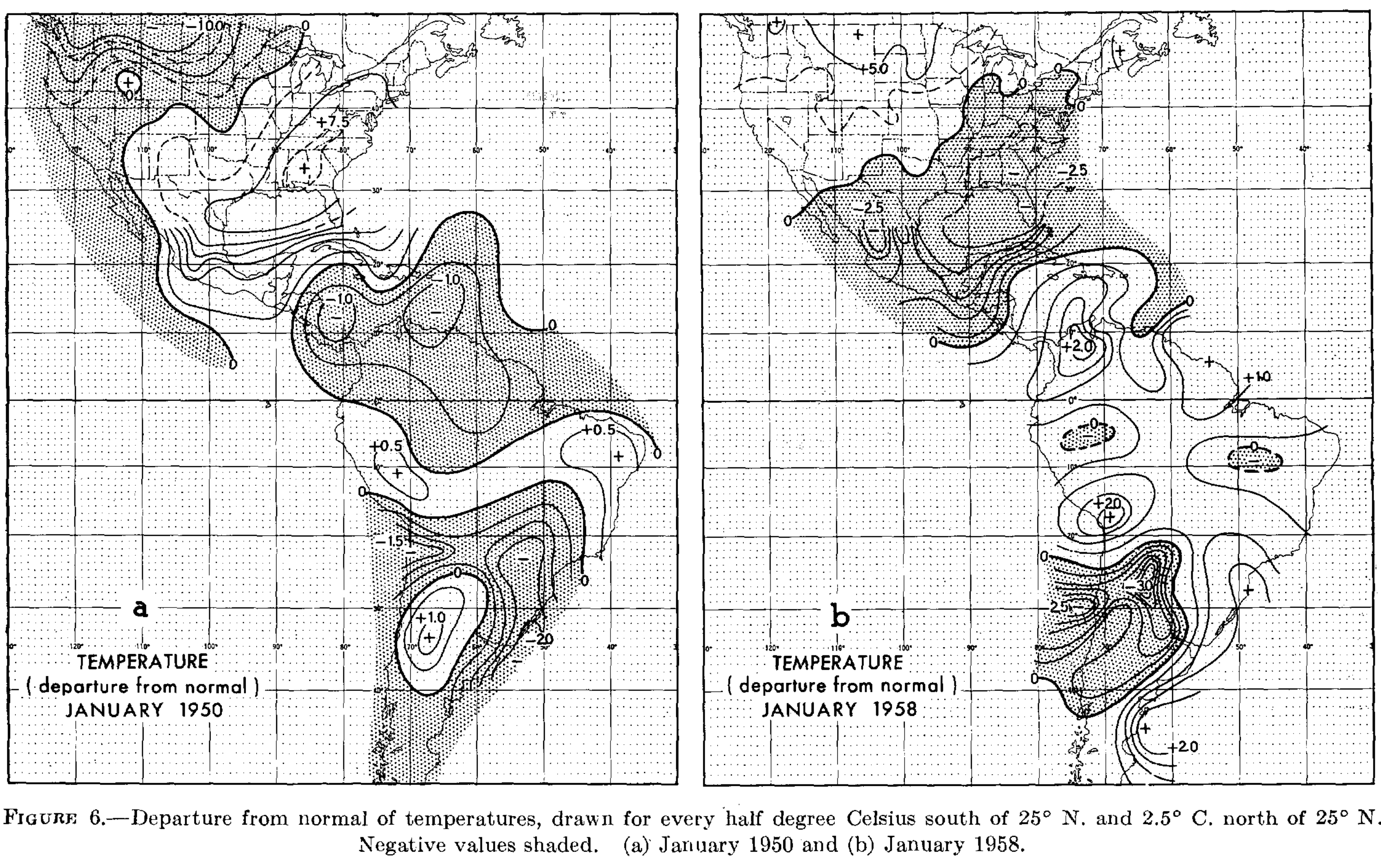

FIGURE 6.—Departure from normal of temperatures, drawn for every half degree Celsius south of 25° N. and 2.5° C. north of 25° N. Negative values shaded. (a) January 1950 and (b) January 1958.

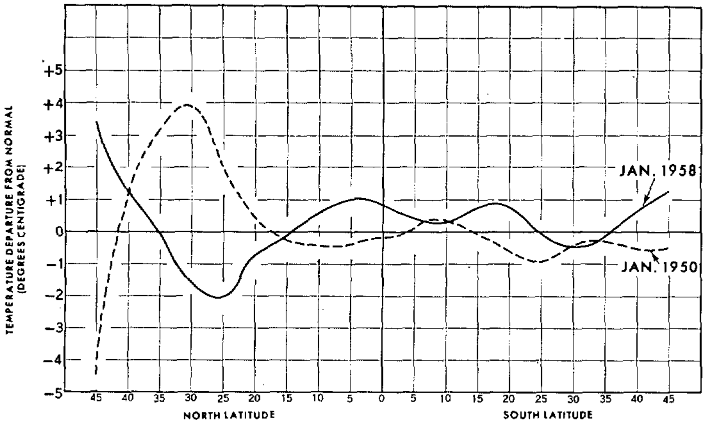

FIGURE 7.—Latitudinal profile of temperature anomaly (°C.) derived from figure 6. Solid curve, January 1958; dashed, January 1950.

(figs. 6a and 6b). Of course, the opposition in the United States reflects the entirely different deployment of air masses as described previously. In the lower latitudes of North America and in much of South America it is clear from figures 4 and 6 that the wet areas were characterized by coolness relative to normal and the dry areas by warmth. This results from the fact that increased cloudiness associated with increased rainfall screens the insolation while the relatively dry areas permit more insolational heating. These radiative factors usually dominate the temperature regime at low latitudes and (during summer) over temperate continental areas. The opposition as well as the latitudinal banding may be seen in figure 7, which has been prepared in the same way as figure 5.

Finally, we shall speculate about causes of the phenomena described. In the first place it is clear that a tight girdle cannot be fixed around the earth's atmosphere at any latitude, for it must be free to respond to many actions from distant sources. Some of the most important of these interactions within one hemisphere (the Northern) have been identified through planetary wave dynamics [5] and also by synoptic-statistical studies of blocking [3]. However, it seems plausible that on occasion a series of standing waves might be generated in a meridional direction and might encompass the equatorial (doldrum) belt as well as the temperate and polar latitudes. These standing waves running through the Tropics and into the Southern Hemisphere might be transmitted in part by the Hadley cell whose position, as we have described, is regionally variable and tuned to the troughs and ridges of amplified quasi-stationary planetary waves. The ascending branch of the Hadley cell would then be variable not only in latitude but also in intensity, depending upon its source of moisture and thus its latent-heat supply. The horizontal extent of this cell would obviously influence the subtropical cells of descending air on its flank, and these in turn could spread influences poleward.

Thus the hopes for truly global weather maps and predictions, so frequently expressed in the late Dr. Wexler's stimulating conversation, papers, and talks may someday become a reality and form another testimonial to his foresight.

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