A STUDY OF THE RAINFALL PATTERNS AND SOME RELATED FEATURES IN A DISSIPATING HURRICANE

By Sterling C. Gilbert and N. E. LaSeur

Florida State University[1,2]

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ABSTRACT

A detailed investigation of the hourly rainfall patterns accompanying a dissipating hurricane over the southeastern United States demonstrates the pronounced asymmetry in the decay of release of latent heat, the primary energy source of the storm. This appears to be associated with the incorporation into the storm circulation of dry air in the layer from 800 to 400 millibars. This air is first drawn in from the outer portions of the left-front quadrant, then sweeps rapidly around the storm into the right-rear and right-front quadrants.

1. Introduction

Hurricane "Florence" of 1953 is the most recent tropical storm to provide an opportunity for first-hand observations at Florida State University.[3] These observations and experiences are responsible for the choice of this hurricane for more detailed investigation. While the study included all phases of its life history, from the formative stages on 23 to 24 September, to its dissipation on 26 to 27 September, the most interesting results emerged from the study of rainfall patterns during the dissipating stages. The primary purpose of this article is to present a description of these rainfall patterns. Secondarily, we will discuss briefly the results of attempts to determine the factors responsible for the observed distribution of precipitation. These attempts, however, cannot be said to have produced concrete results, and no definite conclusions can be drawn. This, in part, is due to inadequate data, particularly in the upper air.

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[2] Mr. Gilbert's present affiliation: U. S. Weather Bureau.

[3] *Editor's note.* Hurricane "Flossy" of 1956 appeared subsequent to completion of this study.

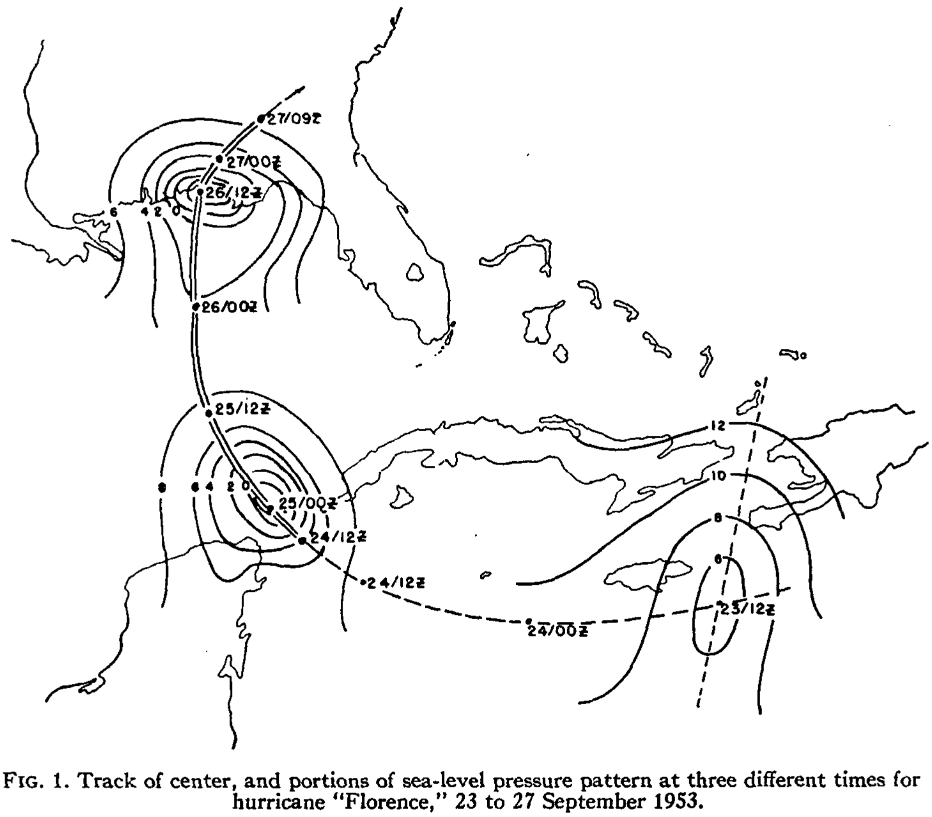

FIG. 1. Track of center, and portions of sea-level pressure pattern at three different times for hurricane "Florence," 23 to 27 September 1953.

TABLE 1. Rainfall amounts (in) for selected stations, in hour ending at indicated time (GCT) on 26 September 1953.

Station	06	07	08	09	10	11	12	13	14	Time 15	16	17	18	19	20	21	22	23	24
Apalachicola, Fla.	.88	.53	.66	.32	.41	.05	.00	.00	.00	.00	.00	.01	.02	.00	.00	.00	.00	.00	.00
Crestview, Fla.	.10	.14	.22	.32	.35	.32	.30	.60	.87	1.51	2.05	.55	.15	.09	.01	.00	.02	.05	.08
Niceville, Fla.	.05	.15	.30	.30	.45	.49	.75	.70	.80	1.50	.95	.45	.10	.05	.00	.00	.00	.06	.03
Lamont, Fla.	.09	.10	.23	.52	.22	.24	.30	.80	.87	1.41	.09	.01	.00	.00	.05	.00	.00	.00	.00
Valdosta, Ga.	.01	.01	.12	.23	.17	.21	.21	.11	.32	.25	1.01	1.57	.52	.03	.01	.01	.01	.00	.00
Hazelhurst, Ga.	.29	.11	.10	.14	.32	.34	.44	.37	.40	.34	.45	.36	.19	.35	.88	.65	.03	.01	.01
Bellville, Ga.	.14	.10	.29	.41	.23	.10	.09	.19	.42	.47	.55	.42	.53	.22	.20	.28	.85	.39	.08

Fig. 1, which briefly summarizes the life history of this hurricane, shows the path of the storm center and the sea-level pressure pattern at three times. The hurricane reached its greatest intensity, as measured by minimum central pressure (968 mb) and maximum surface winds (≈ 110 kn), near its westernmost position as it recurved on 25 September. Some decrease in intensity appears to have taken place by the time it moved inland between Pensacola and Panama City, Florida. Maximum reported winds were 80 to 85 kn in gusts, and minimum measured pressures were only a little less than 990 mb. However, the center of the storm passed over a relatively sparsely inhabited region without weather-reporting stations, so that stronger winds and lower pressures than those recorded probably occurred.

For more than 30 hr after entering the coast, the storm remained as a clearly identifiable center of low sea-level pressure with the accompanying cyclonic-inflow pattern of surface winds. It weakened steadily until, by 1830 GCT 27 September 1953, the central pressure was about 1002 mb and surface winds had generally decreased to 15 kn. The symmetry of the storm was not distorted by the development of strong frontal zones. Only to the northeast, where a pre-existing, weak warm front was subject to some frontogenesis, did a sea-level pressure trough radiate from the center. Despite this lack of asymmetry in the pressure and wind fields, the rapid development of marked asymmetry in the rainfall patterns was quite apparent. Already at the time the storm crossed the coastline, there appeared in the right-rear quadrant,

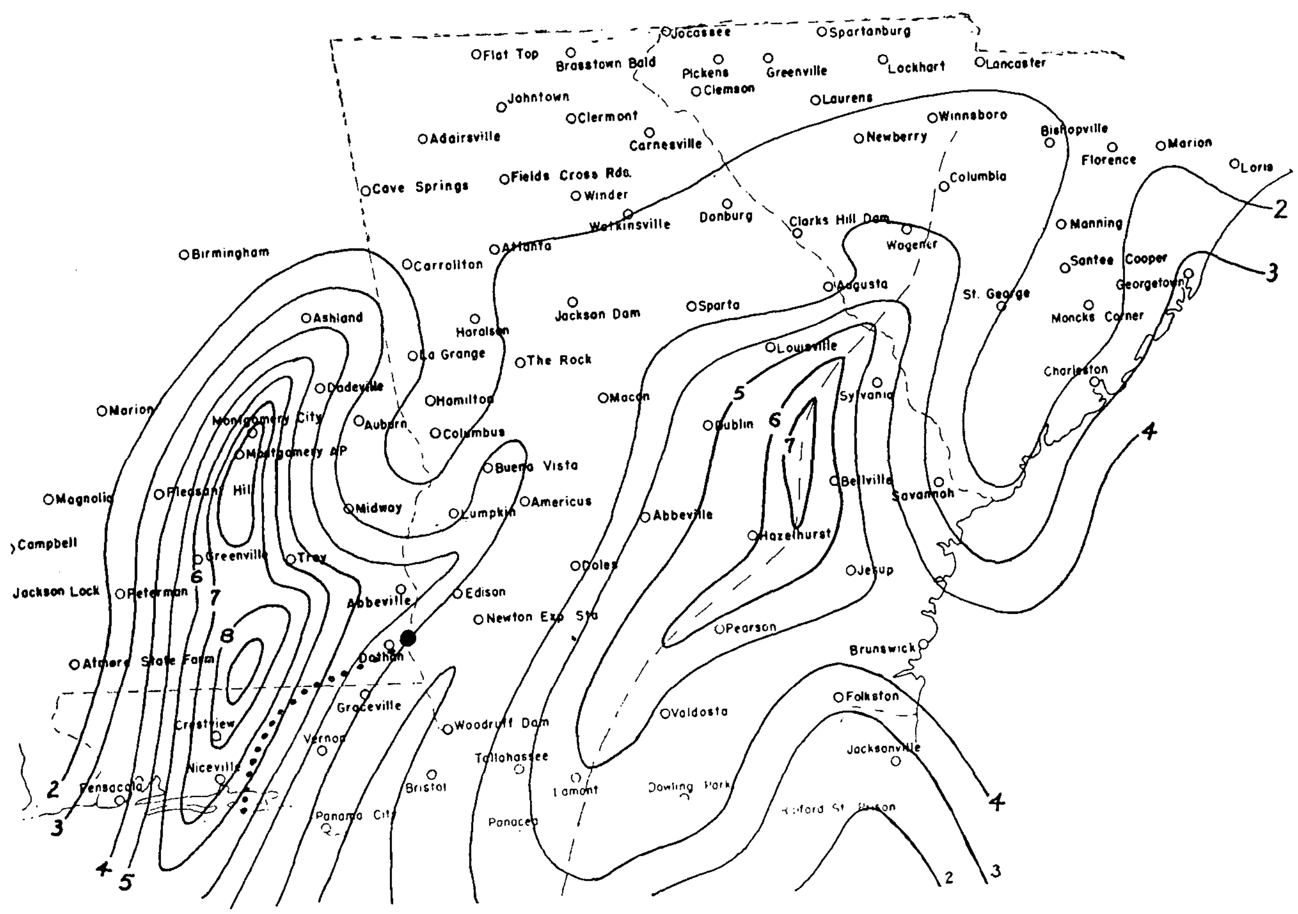

FIG. 2. Isolines of 24-hr total rainfall (in) for period 0500 GCT 26 September 1953 to 0500 GCT 27 September 1953.

at a radius of about 50 to 100 mi from the center, an area in which rainfall ceased abruptly; stations farther from, and closer to, the center were still experiencing moderate to heavy rain. This area of little or no rainfall spread rapidly into the right-front quadrant of the storm and outward from the center. Heavy rain fell to the left of the center. Thus, while the symmetry of the pressure and wind fields did not disappear rapidly, the rainfall patterns suggested that the decay of the principal energy source of the hurricane, the release of latent heat, was by no means distributed symmetrically.

2. Rainfall patterns

Twenty-four hour total rainfall.—The significant features of the rainfall patterns will be illustrated by the period from 0500 GCT (0000 EST) 26 September to 0500 GCT (0000 EST) 27 September. Fig. 2 presents an analysis of the 24-hr total rainfall during this period. The principal source of data was the published U. S. Weather Bureau *Hourly Precipitation Data*, supplemented by 24-hr amounts from other available stations. The position of the hurricane at the beginning of this period was 100 mi almost due south of its point of entry. Its track after crossing the coast to its position at 0500 GCT 27 September 1953 (heavy dot) is shown by the dotted line. Two maxima dominate the 24-hr pattern, one to the left and one to the right of the storm track. These maxima are similar in shape and central value, but result from very different hourly rainfall patterns as will be seen. Note that, even in the pattern of 24-hr total rainfall, a relative minimum lies just to the right of the storm track.

Hourly rainfall amounts.—Although charts of the hourly rainfall amounts were analyzed for each hour, it will suffice to present only a selection, mostly at 3-hr intervals. Fig. 3 gives the analysis of rainfall amounts during the first hour of the period. Only the coastal regions in the right-front quadrant of the storm, which is still nearly 100 mi south of its point of entry, are receiving heavy rainfall amounts. The maximum reported value is 0.88 in at Apalachicola (table 1). The band of rainfall in south Georgia is less directly related to the hurricane, at least in part being associated with a weak warm front in that area. These two general features persist throughout the next 6 hr with slow development, and can still be recognized in the pattern of rainfall amounts 6 hr later during the hour ending at 1200 GCT 26 September 1953 (fig. 4). At this time, the storm center, indicated by the heavy dot in fig. 4, is just crossing the coastline. A cyclonically curved arc of heavy rainfall amounts curves from a position on the coast south of Tallahassee first northwestward, then westward and southwestward to

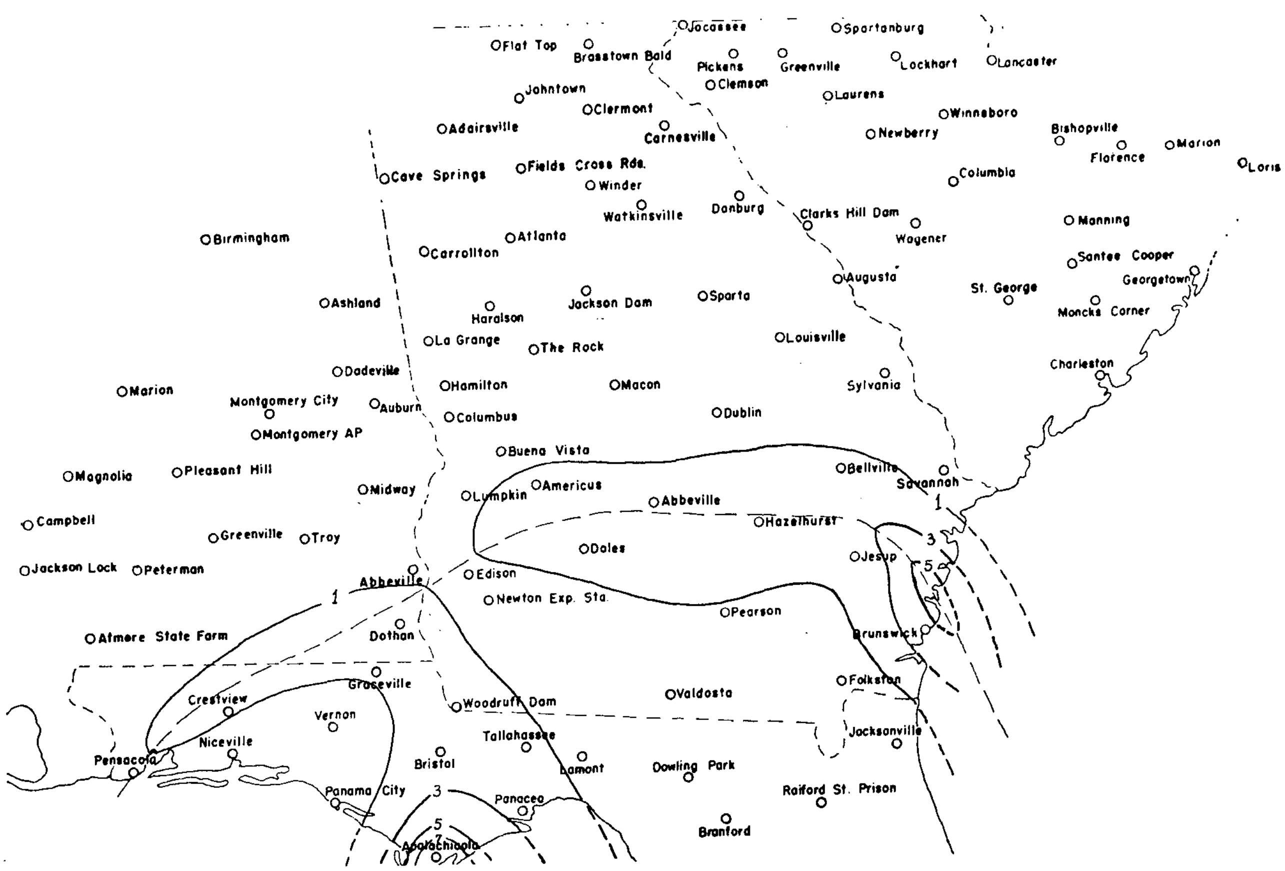

FIG. 3. Isolines of hourly rainfall amounts (tenths of inches) for hour ending 0600 GCT 26 September 1953.

Pensacola. Intervening hourly maps show this rainfall area to have moved slowly inland as the storm center approached, and strongly suggest that centers of maximum intensity of rainfall move cyclonically along the general axis of large precipitation amounts. This also holds true for the rainfall area in southern Georgia which remains quasi-stationary as a whole, but consists of individual centers of maximum amounts moving inland from the sea in a westerly to northwesterly direction. Of special importance is the area of minimum rainfall amounts which appears just to the right of the storm center. Here, in contrast to stations located west of the center which have received more than 0.7 in of rain in the past hour, rainfall amounts fall below 0.1 in and rain has ceased by the end of the hour. We will follow closely the development of this relatively rainless area on subsequent charts.

Three hours later, an analysis of the hourly rainfall amounts (fig. 5) shows the area of minimum rainfall has moved farther inland ahead of the storm center and nearly separates the previous cyclonic arc of maximum rainfall into two centers. Stations just west of the center recorded 1.5 in of rain in the past hour and Lamont, Florida, just east of Tallahassee, had 1.4 in; but Apalachicola has had no rain in the past three hours (table 1). The band of rainfall in southern Georgia still exists, oriented approximately east–west, nearly parallel to and just north of a weak warm front which extends westward toward the storm center.

Fig. 6 presents an analysis of rainfall amounts for the hour ending at 1800 GCT 26 September 1953, three hours after fig. 5. The two principal areas of heavy rainfall are still evident over southeastern Alabama and south central Georgia. The expanding, nearly rainless area separates them. The displacement of the eastern maximum during the previous 3 hr corresponds to a speed of 20 to 25 kn. Gradients of rainfall intensity, in reality, are probably greater than the analysis indicates, since the isolines of the figure can only be interpreted as rainfall intensities averaged over a 1-hr period. Even these values show extreme changes, particularly just after the rainfall maximum passes. The values in table 1 illustrate this for several of the stations passed by the eastern maximum, and for other selected stations. This maximum passed near Tallahassee, where the rain ceased abruptly at 1610 GCT, consistent with the recorded values at Lamont about 25 mi to the east. Similar rapid decreases in rainfall amounts occur at stations just west of the storm center, as the western maximum passes northward only slightly faster than the 5-kn speed of the storm (see Crestview and Niceville values in table 1).

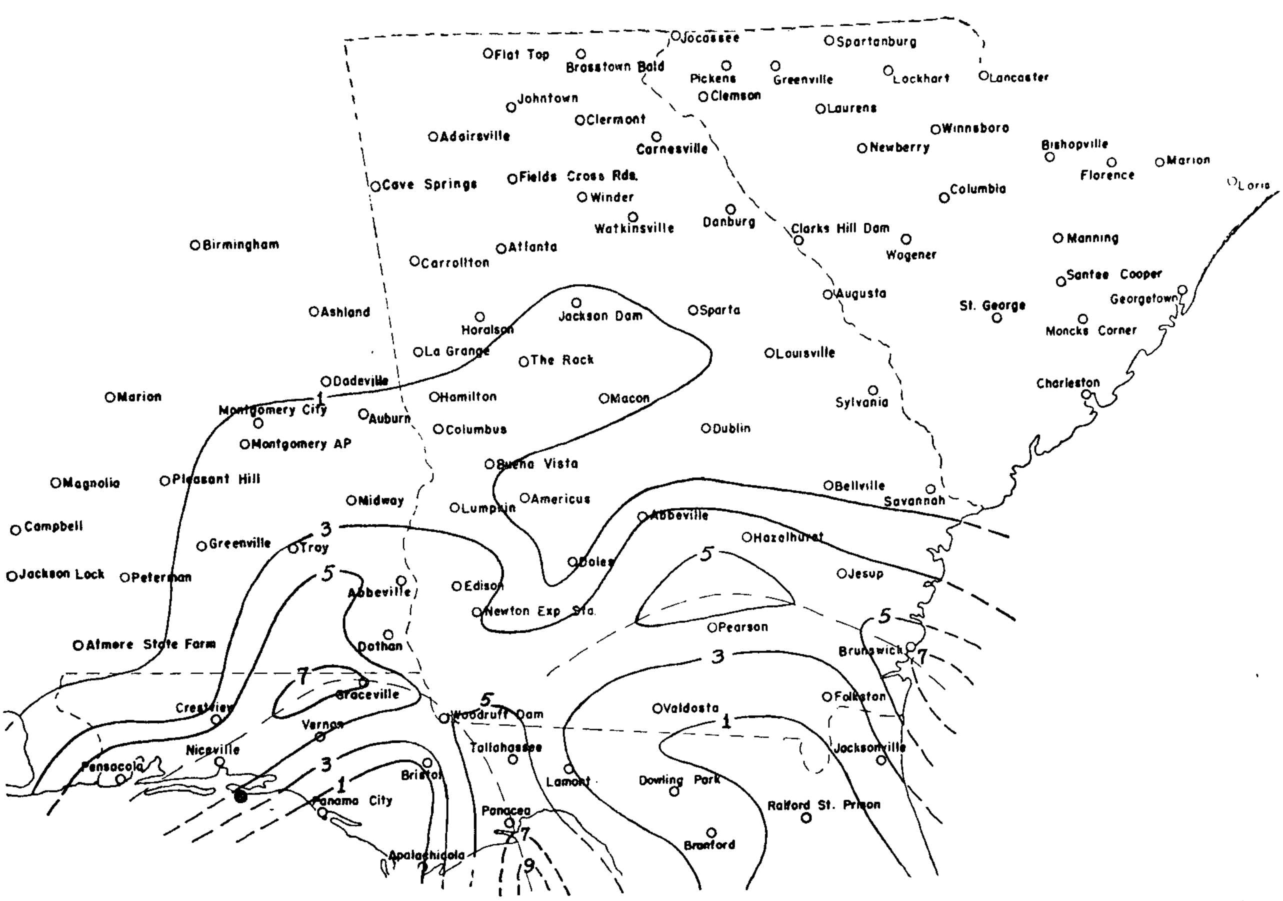

FIG. 4. Same as fig. 3, but for hour ending 1200 GCT 26 September 1953.

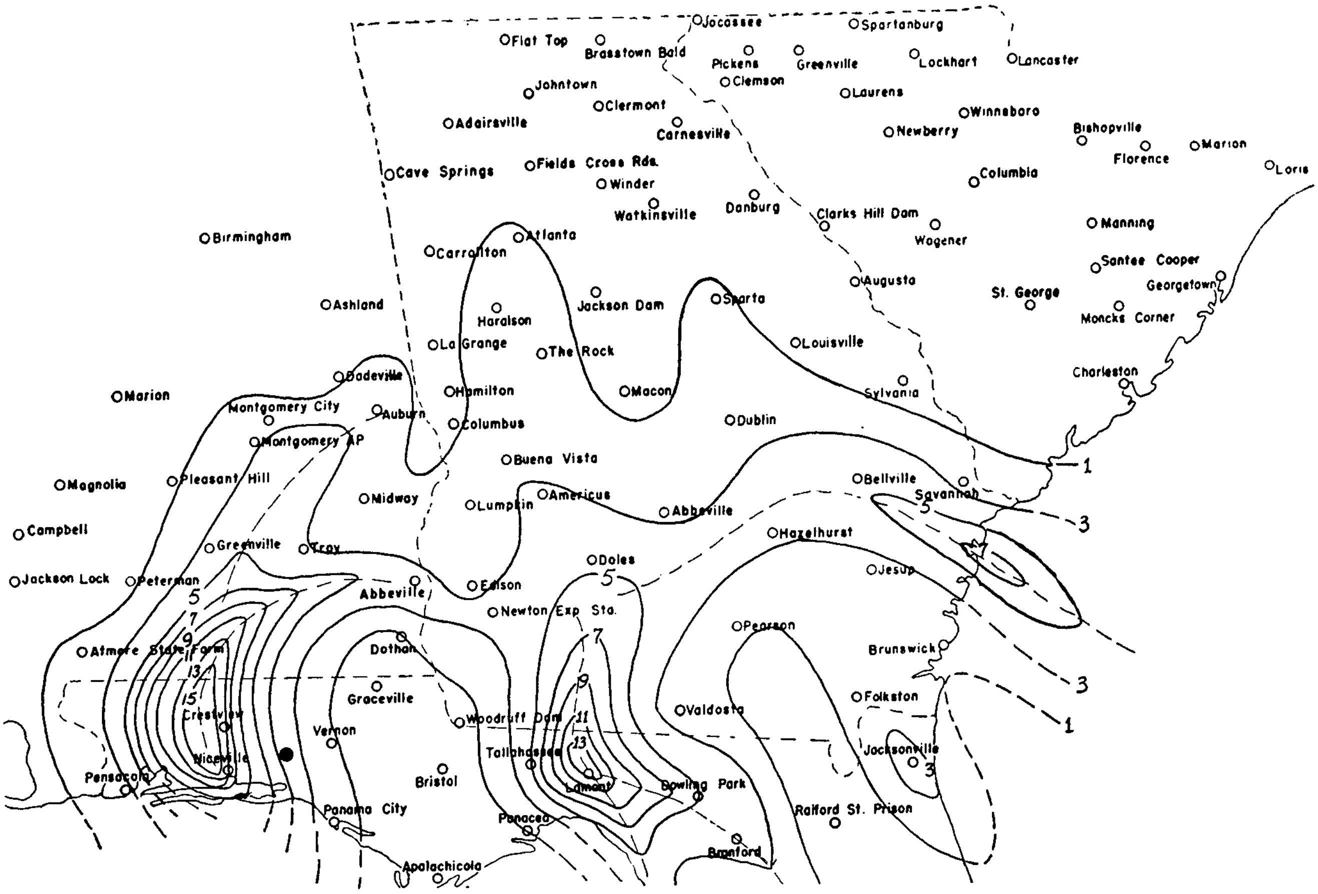

FIG. 5. Same as fig. 3, but for hour ending 1500 GCT 26 September 1953.

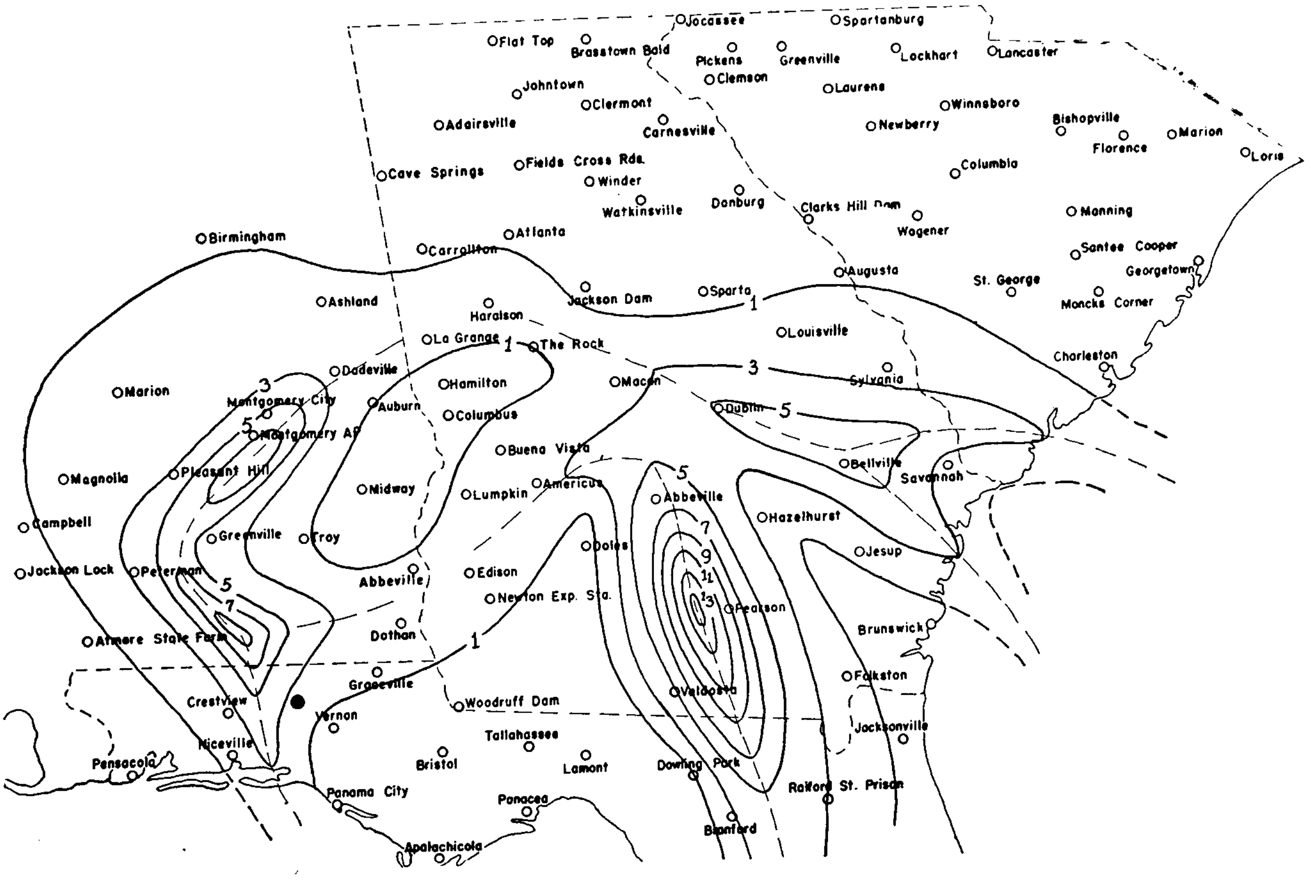

FIG. 6. Same as fig. 3, but for hour ending 1800 GCT 26 September 1953.

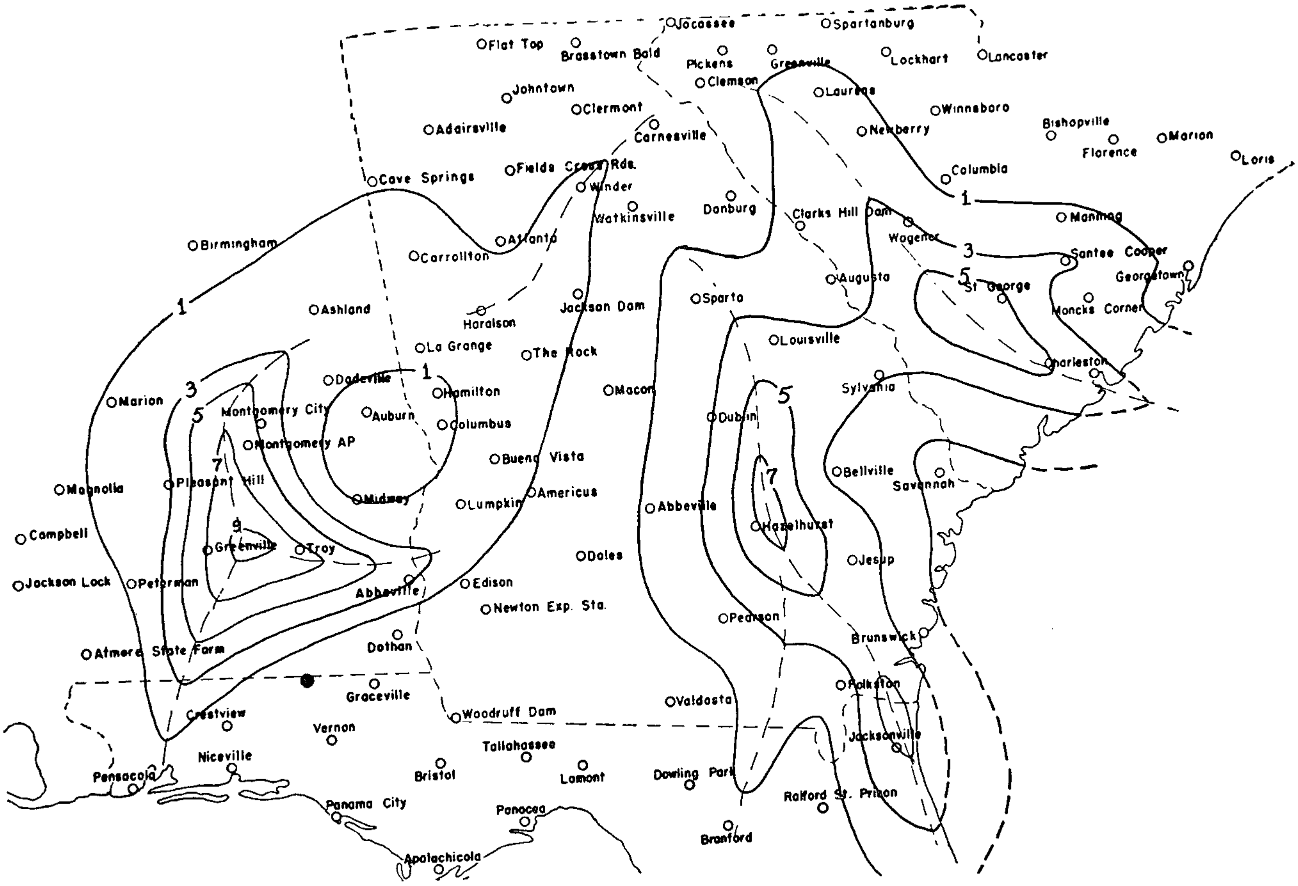

FIG. 7. Same as fig. 3, but for hour ending 2100 GCT 26 September 1953.

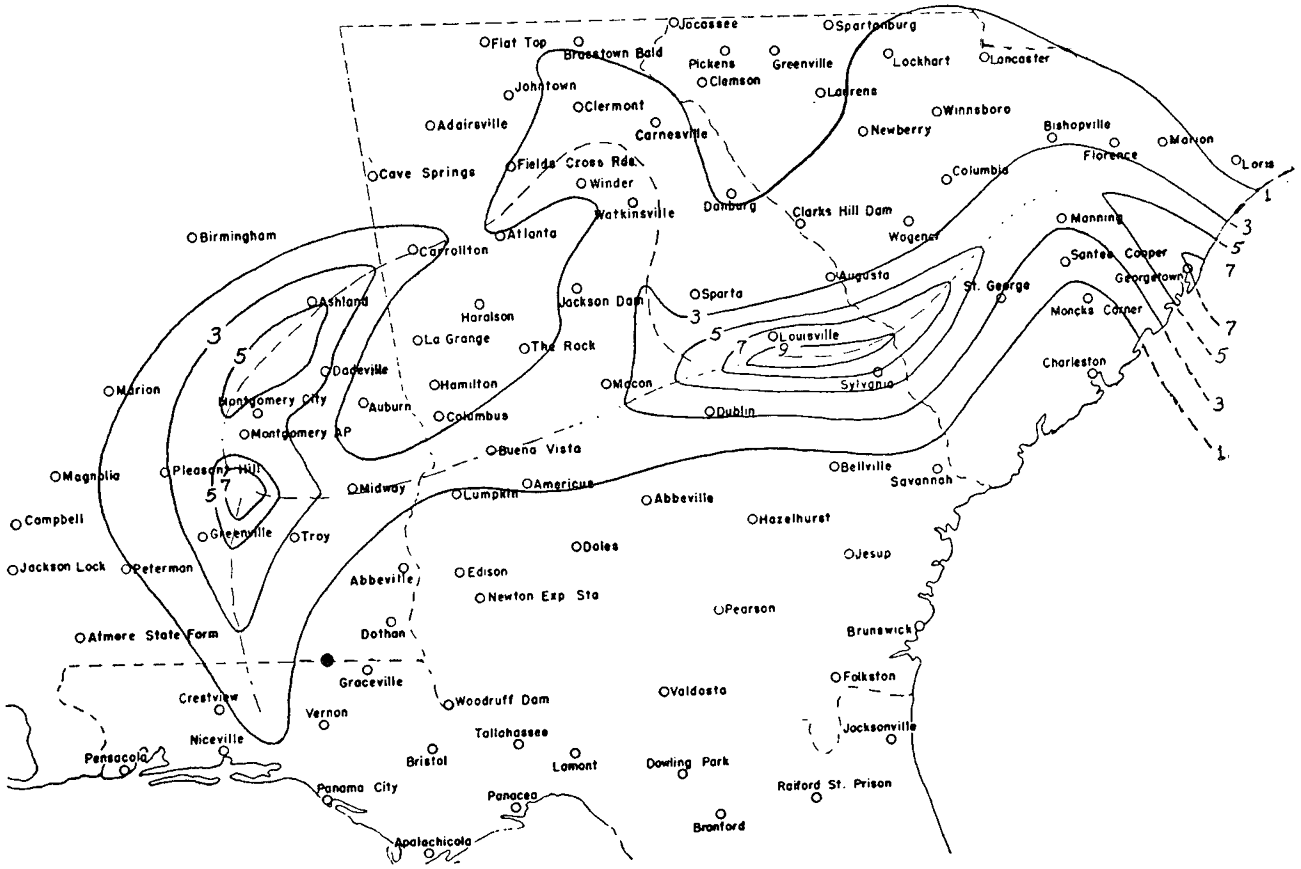

FIG. 8. Same as fig. 3, but for hour ending 0000 GCT 27 September 1953.

The secondary maximum in east central Georgia can be identified with the previous maximum in that area.

Three hours later (fig. 7), the eastern maximum is just past Hazelhurst, Georgia, a displacement of about 70 mi in the 3 hr. The western maximum in southeastern Alabama has not moved as far, but its displacement has increased over that of the previous 3 hr. Both have diminished in intensity. The area of less than 0.1 in of rainfall per hour continues to expand.

Fig. 8 gives an analysis of the hourly amounts of rainfall ending 3 hr later, at 0000 GCT 27 September 1953. The eastern maximum is in east central Georgia, again a displacement of about 70 mi in 3 hr. The western maximum appears to have a double structure again, which makes it difficult to estimate movement, but it is more slowly moving in any case. This general pattern of motion continues for the remaining 5 hr of the period (see figs. 9 and 10). The eastern maximum is found in north central South Carolina by 0500 GCT 27 September 1953, while the western maximum is in east central Alabama. Especially the western maximum was weakened. Rainfall has practically ceased throughout northern Florida and all of Georgia (table 1), though the remnants of the hurricane have moved only to the position indicated by the heavy dot in fig. 10.

After this review of a portion of the hourly rainfall charts, the chart of the 24-hr totals (fig. 2) is more meaningful. It is clear now that the two principal maxima of 24-hr amounts, one in southeastern Alabama and the other in southeastern Georgia, result from different hourly patterns. The western maximum results from a slowly moving area of heavy hourly rainfall to the left of and relatively near the storm center, while the eastern maximum results from a rapidly moving center of heavy hourly amounts which moves twice to three times as fast as the storm center and is never closer than about 150 mi. The minimum separating these maxima lies 30 to 50 mi to the right of the storm path and results from a nearly rainless tongue which appears first in the right-rear quadrant of the storm and spreads rapidly into the right-front quadrant.

The two rainfall maxima described above are undoubtedly remnants of the well-known spiral bands of convection associated with tropical cyclones. However, these maxima do not move as one would expect if they are simply band remnants. This is more clearly shown by plotting their tracks in a coordinate system moving with the storm center, which removes the translation of the storm. In such a system, one would expect band remnants unaffected by other influences

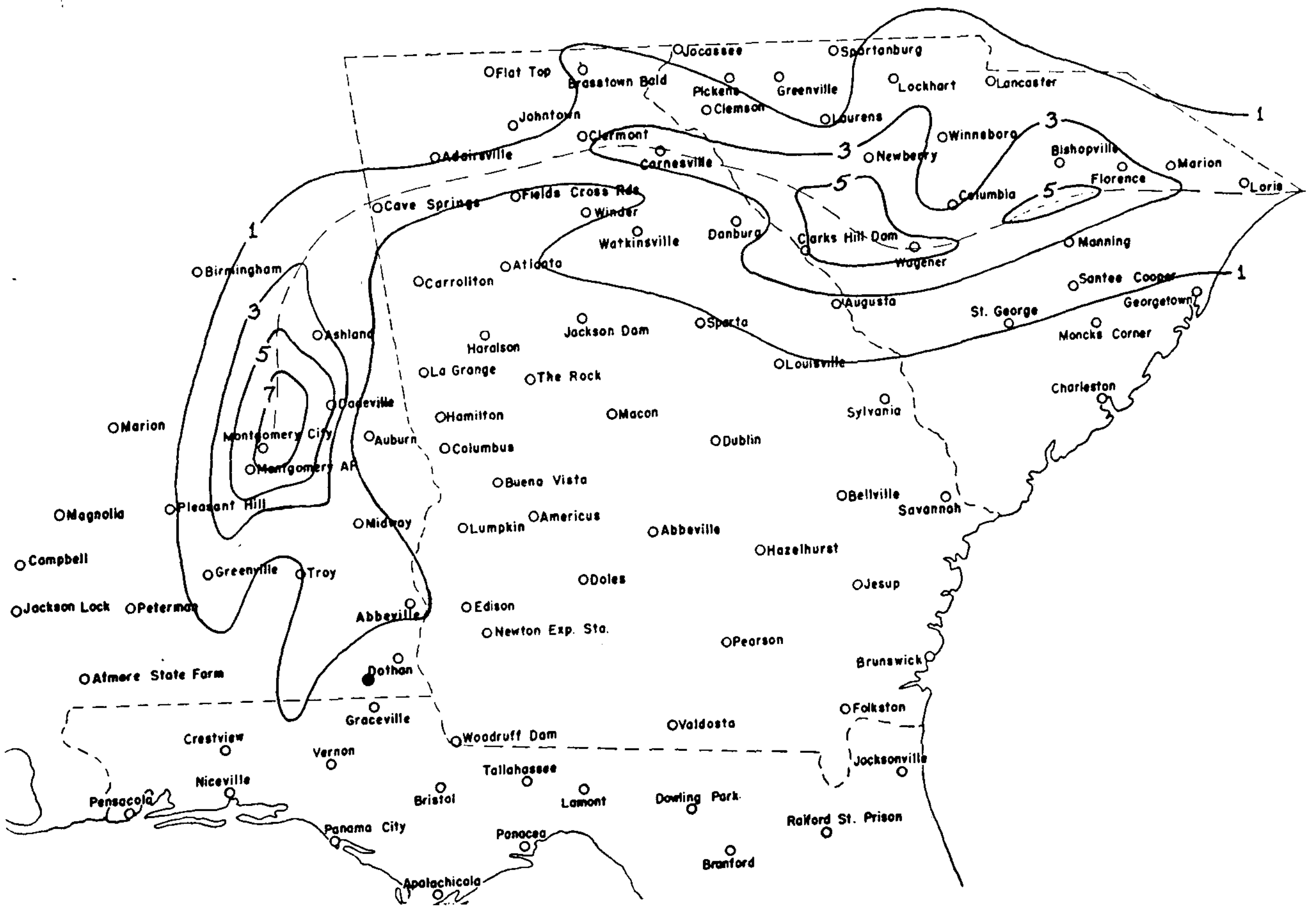

FIG. 9. Same as fig. 3, but for hour ending 0300 GCT 27 September 1953.

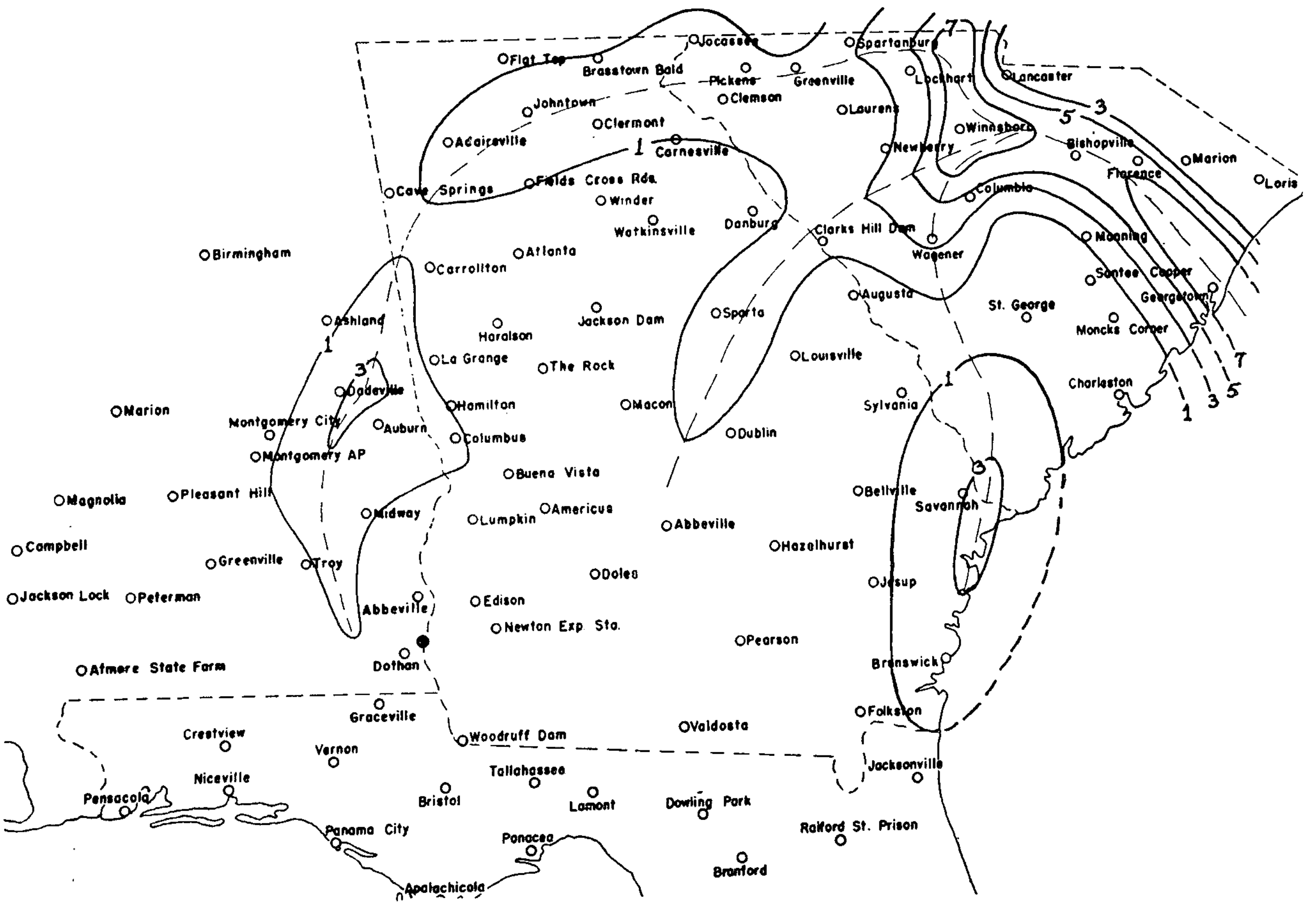

FIG. 10. Same as fig. 3, but for hour ending 0500 GCT 27 September 1953.

to show predominantly cyclonic rotation about the storm center with some inflow component. Fig. 11, in which the positions of the rainfall maxima have been plotted with respect to the location of the storm center at 1500 GCT 26 September 1953, shows both maxima move outward from the storm center. The outward movement is greater for the eastern maximum which does show some cyclonic rotation, but the western maximum actually moves anticyclonically with respect to the storm center.

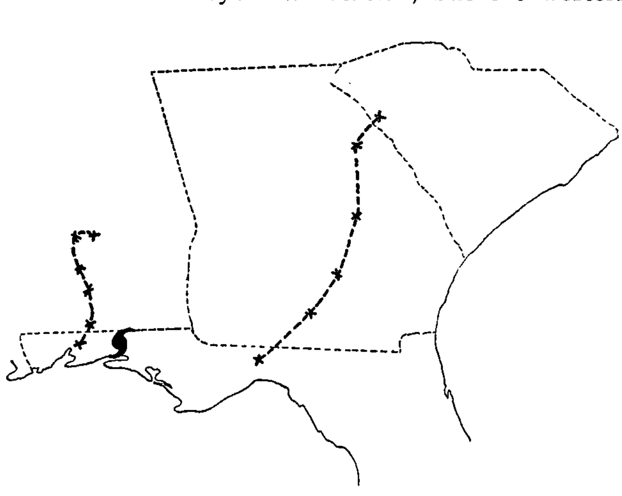

FIG. 11. Track of two main maxima of hourly rainfall amounts in coordinate system which removes translation of storm. Reference position of storm center at 1500 GCT 26 September 1953.

Extensive analysis of the fields of motion, pressure, temperature and humidity was carried out at the surface, 850, 700, 500 and 300 mb to determine what, if any, features could be detected and associated with the observed modification of the usual spiral-band structure which took place as the hurricane dissipated over land. In addition, all pertinent upper-air soundings were plotted. The stations reporting hourly rainfall amounts provide the most dense network of data. About half as many stations provide hourly surface observations, and about a tenth report winds-aloft, radiosonde or rawinsonde data. Thus, the chances of isolating and describing such associated features are diminished by the decreasing density of surface and upper-air observations. Streamlines of the surface winds, and sea-level isobars and isallobars, drawn at hourly intervals did not reveal any features which could clearly be associated with the rainfall patterns. Fig. 12 presents an example of surface streamlines and sea-level isobars. The largest hourly rainfall amounts during the hour centered on this map time (see fig. 6) occur just west and northwest of the center, over extreme northwest Florida and southeastern Alabama, and more than 100 mi east of the center over south

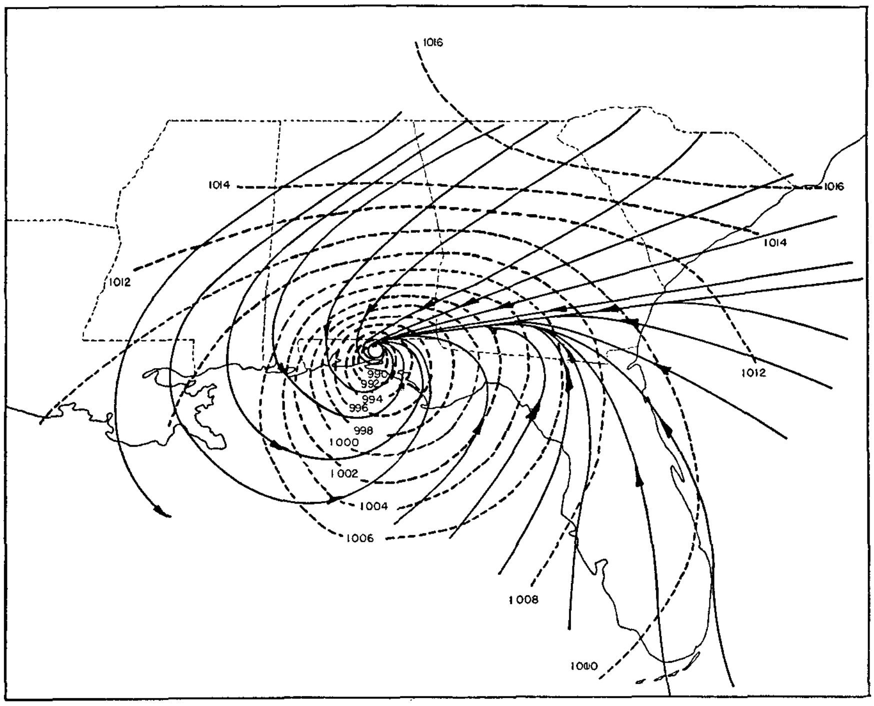

FIG. 12. Streamlines of surface wind (solid lines), and sea-level isobars (dashed lines) at 1730 GCT 26 September 1953.

central Georgia. Some arguments could be advanced to associate the rainfall maxima with some features of the surface map, particularly in the case of the eastern maximum. But the lack of consistency in the relationships from map to map makes it unprofitable to pursue the matter further. Records at some individual stations passed by the rapidly-moving eastern rainfall maximum showed a tendency for strongest wind gusts to accompany the passage, for larger hourly pressure falls to precede it slightly, and for a cyclonic shift of the surface wind to follow. But these features did not appear consistently at all stations, nor could any quasi-conservative characteristic of the wind or pressure field be followed in continuous association with the rainfall maximum. We conclude that there were, in all probability, variations in surface wind and pressure which accompanied the rainfall maximum, but that these cannot be detected with the existing network. This is in part due to the fact that the eastern rainfall maximum moved through a region with fewer reporting stations than elsewhere.

Analysis of the upper-air data does suggest strongly

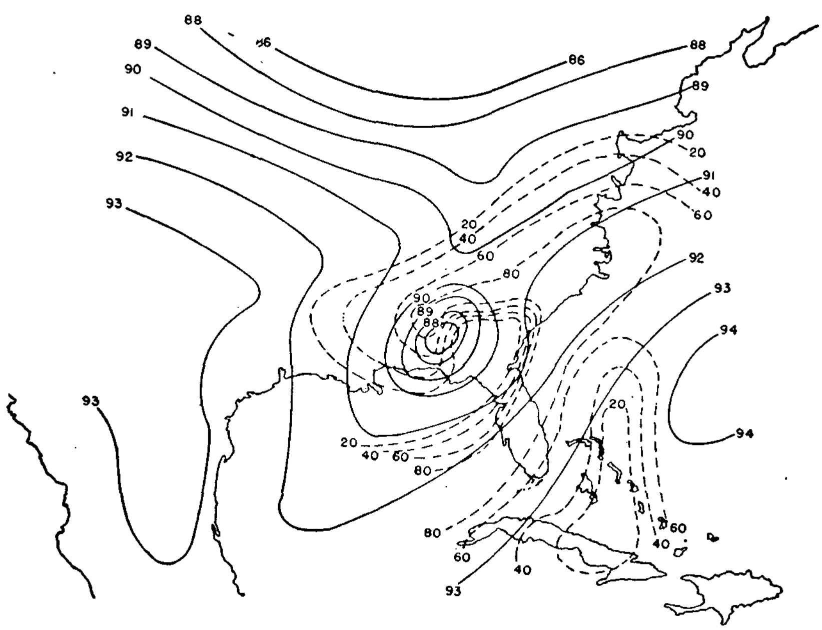

FIG. 13. Height contours (solid lines) and isolines of relative humidity (dashed lines) at 500 mb, 0300 GCT 27 September 1953.

one factor which may have had a significant influence on the observed modification of the rainfall bands. This feature was in the humidity field in the layer from about 800 to 400 mb. As the hurricane approached, humitity values were high at stations along the Gulf coast from Burrwood, Louisiana, to Florida, in contrast to an extensive area in the southern regions of the Mississippi Valley and Great Plains where above about 800 mb the radiosonde reports indicated "motor-boating" in very dry air. As the hurricane moved inland, it appears that some of this air was drawn into its circulation with the dry air aloft forming a tongue which swept cyclonically around the storm, entering Florida and Georgia as a southwesterly current. The advection of this dry air aloft would have a powerful inhibiting effect on the development of convective clouds, even if the lower wind field were convergent. It is probable that descent also occurred in this current, though data are insufficient to warrant computation of divergence, vertical motions, or trajectories. Fig. 13 shows the 500-mb chart for 0300 GCT 27 September 1953, in which, besides the contours (solid lines), the field of relative humidity has been analyzed (dashed lines). Although alternative analyses are possible, we believe the one shown to be the more correct. The correspondence with the general rainfall pattern at that time (fig. 9) is obvious.

3. Summary and conclusions

The decay of this hurricane was quite symmetrical and not rapid, in terms of the pressure and wind fields. This aspect of the decay is undoubtedly due to the combined effects of the elimination of the internal heat source and of frictional filling after moving over land, plus the gradual influx of surface air whose thermal and moisture values, though not markedly lower, could no longer maintain the required hurricane structure (see Riehl [1], chapter 11). Superimposed on this gradual, symmetrical decay, and revealed most clearly by a detailed study of the modification undergone by the convective bands as shown by the hourly rainfall amounts, is an asymmetrical decay of the release of latent heat. No definite conclusions can be drawn as to the factors responsible for this. But it is suggested that one contributing influence is the inhibitory effect of the advection of very dry air in the layer from about 800 to 400 mb, which sweeps around the storm from the northwest and, moving much faster than the storm, rapidly penetrates into the right-rear and right-front quadrants as a southwesterly current. Maximum rainfall at many stations occurs shortly before its arrival, and then ceases abruptly, although surface humidity decreases but little.

REFERENCE

1. Riehl, H., 1954: *Tropical meteorology.* New York, McGraw-Hill, 392 pp.