UDC 551.577.37:551.515.2:556.166.4(755) "1969.08.19-20" CAMILLE

THE UNPRECEDENTED RAINS IN VIRGINIA ASSOCIATED WITH THE REMNANTS OF HURRICANE CAMILLE

FRANCIS K. SCHWARZ

Office of Hydrology, Weather Bureau, ESSA, Silver Spring, Md.

ABSTRACT

The rainfall and synoptic features of the unprecedented Virginia storm associated with the remnants of hurricane Camille are analyzed. Comparisons with alltime record-breaking rains in the United States and probable maximum precipitation estimates are made. The rains of this storm are shown to come within 80 to 85 percent of the probable maximum precipitation for a duration of 12 hr for areas up to 1,000 mi^2.

Persistent low-level moisture feeding into the remains of Camille's cyclonic circulation was found to be close to the maximum persisting value for the season and location. The passage of the remnant low-pressure system a little to the south of the rain area resulted in low-level flow from the southeast which made it possible to utili ze the high moisture, with some orographic intensification, without depletion by upwind barriers.

Apparently, in addition to the very high moisture values, a number of synoptic and mesoscale weather factors operated properly to produce the remarkable rainfall.

1. INTRODUCTION

As the remnants of Camille moved across Virginia the night of August 19–20, alltime record rains for Virginia occurred. The result was "the most severe flooding of the James River and its tributaries in nearly a century" (Environmental Science Services Administration and Statistical Reporting Service 1969).

Synoptic and mesoscale features of this unusual storm are investigated with a view to suggesting why the rains were so heavy. Extremely rare weather events, such as this, must come from an extremely rare combination of rain-producing and rain-intensifying factors. Explanations adequate for moderately heavy rains fall short in explaining the extreme event. This fact is kept in mind in the discussion of the accompanying weather features.

2. THE RAINFALL

Rainfall from hurricanes that enter the States bordering the Gulf of Mexico typically is the most intense within 100 mi or so of the coast. Hurricane Camille was atypical—the most intense rains occurred in Virginia, far removed from Camille's point of entry in Mississippi.

The heaviest rainfall associated with Camille at the Gulf Coast was 9.4 in. measured at Picayune in the southeast corner of Mississippi. Farther along its path northward across the State, rains diminished rapidly to less than 3 in. approximately 150 mi inland. In western Tennessee and western Kentucky, the heaviest reported rains were generally between 2 and 3 in. After the storm turned to the east in western Kentucky, rains intensified, with some reported values over 4 in. in eastern Kentucky and southern West Virginia.

Before the remnant low-pressure circulation of Camille crossed the Blue Ridge in Virginia, a deluge commenced. Several regularly reporting stations measured more than 10 in. of rain. In the James River Basin on the eastern slopes of the Blue Ridge, torrential rains were responsible for the worst natural disaster known in Virginia. Flash-flooding and rain-induced mud slides took over 150 lives.

Soon after the storm, a Weather Bureau survey team collecting unofficial rain measurements spent several days in and near the devasted area. Such measurements, for the most part, were made of rain caught in small plastic commercial rain gages, empty trash and paint cans, etc. The survey showed 15 catches of 8 in. or more and four of over 20 in. The greatest amount, 27 in., was measured near Massies Mill, Va.

The Weather Bureau received a report of 31 in. of rain in 5 hr measured at the junction of the Tye and Piney Rivers. Since the timing of rain did not agree with other nearby reports and the catch, if verified, might be a world record, the site was visited by a Weather Bureau representative to more fully document the event. Neither the person who made the observation nor the container that was used could be identified. Therefore, the 31 in. was not used. However, a reliable measurement of 23 in. was obtained for the same general vicinity, indicating that the rainfall was extreme, and that 31 in. may have fallen.

STORM ISOHYETAL MAP

The isohyetal map (fig. 1) was limited on the western edge by the 83d meridian. Rainfall for the period from 0600 EST on the 19th to 1800 on the 20th is included. Generally, the rains lasted for 12 hr or less. Figure 2 shows eight mass rainfall curves (accumulated rainfall with time) for hourly rainfall recorders nearest the heaviest rains. The stations are numbered from west to east—number 1 in eastern Kentucky and number 8 as the most eastern station in Virginia. The locations are identified by numbers at crosses on figure 1. The beginnings and endings of rain and times of maximum 1-hr burst (indicated by

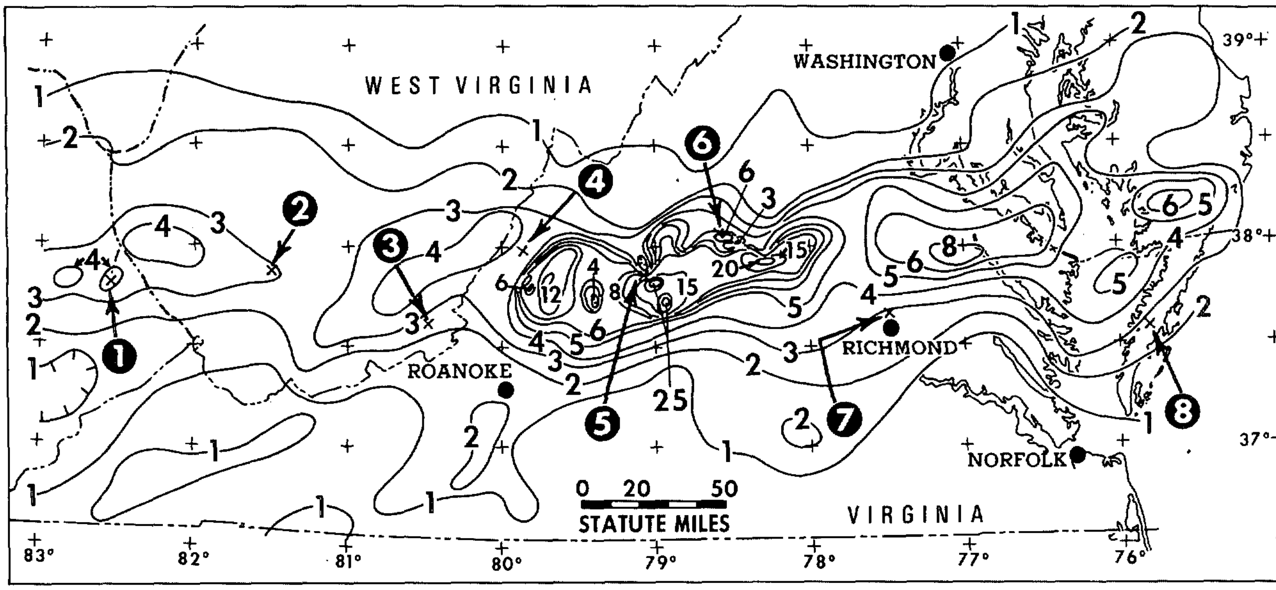

FIGURE 1.—Isohyetal map (inches), 0600 EST on August 19 to 1800 EST on Aug. 20, 1969.

M's in fig. 2) in general show a smooth progression from west to east. There is a tendency for slowest movement between longitudes 80° and 78°, the region with heaviest rains.

The isohyets were drawn quite smooth, without hypothesizing higher centers than indicated by the available observational data. It is very likely that additional higher rainfall centers did exist between observed points. Similarly, there were undoubtedly places where the rainfall was lower than the indicated isohyetal values. Large gradients in rainfall where observations were most dense confirm the complex nature of the rainfall. Theoretically, this character of the rain is reasonable where thunderstorm rains are most intense. For the four observations of over 20 in., less than 6 in. was measured in some direction less than 5 mi away.

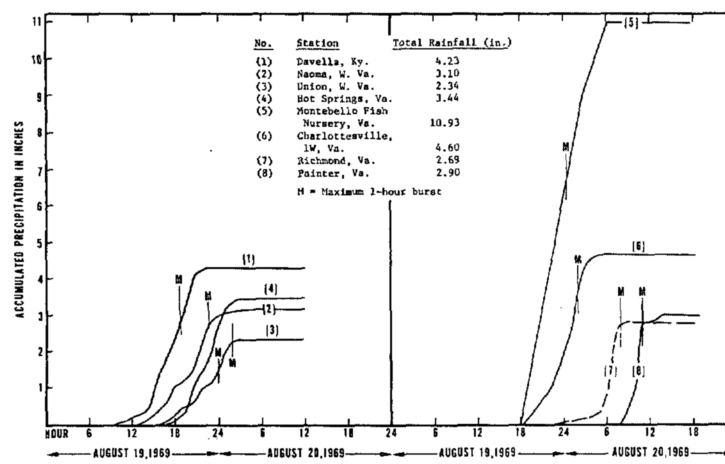

FIGURE 2.—Accumulated rainfall at selected hourly recorder stations.

ROLE OF OROGRAPHY

In a broad sense, terrain was important to the intense rains in Virginia. The Blue Ridge is the boundary between storm rains greater than 10 in. and less than 5 in. This separation, however, may be due to the ridges forming a dam to southeast inflow of moisture (which was near the highest of record) rather than to lifting by southeast-facing slopes.

Triggering of rainfall by relatively slight terrain configurations may have had a part to play in placing of intense rains, although a much more dense rain-gage network would be necessary to verify this effect. For example, the highest storm value of 27 in. near Massies Mill is within a few miles of steep southeast-facing slopes. Another contributing factor at this location may be the narrowing of the valley that could cause horizontal convergence of the moist low-level air. The 25-in. center to the south likewise is near southeast-facing slopes. Not to be overlooked, we have a reported 21+ in. about 15 mi southeast of Charlottesville where terrain is hilly, but there are no major organized steep slopes within 15 mi. From the standpoint of either triggering by foothills or lifting by slopes, many more-favorable locations exist where rain amounts were not extreme.

MAXIMUM AREAL RAINFALL

A detailed analysis of the intense rainfall, giving maximum areal depths in the storm for selected durations, called a depth-duration-area (DDA) analysis, will be carried out by the Corps of Engineers, under a continuing program that provides a catalog of U.S. extreme areal rainfall (Corps of Engineers 1945). For this, mass rainfall curves will be constructed for all reported rains, making use of observers' notes as well as the hourly recorder data.

TABLE 1.—*Camille's rainfall, Aug. 19-21, 1969, centered in Virginia (tentative maximum areal depths for standard size areas and durations)*

Area (square miles)	Duration (hours) 6	12	18
	Rain depth (inches)		
10	18.0	25.2	25.2
100	14.5	20.7	20.7
200	12.9	18.8	18.8
500	10.5	16.2	16.2
1,000	8.7	13.7	13.7
2,000	7.1	10.9	10.9
5,000	5.2	7.7	8.1
10,000	3.8	5.7	6.3
20,000	2.6	4.2	4.8
50,000	1.5	2.6	3.0

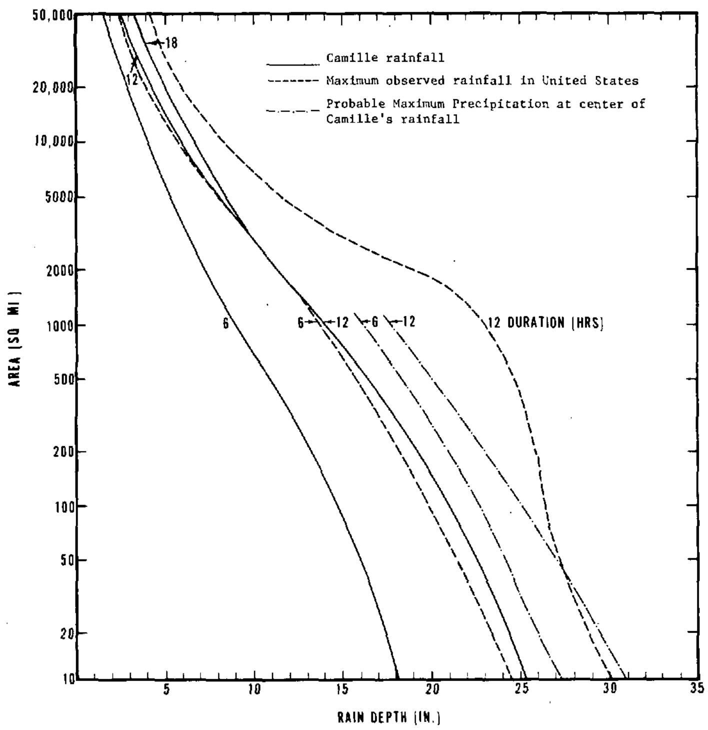

FIGURE 3.—Comparison of rainfall from Camille with maximum observed in the United States and with probable maximum precipitation.

It will be at least several months before this analysis is completed.

For our study, we have made a tentative DDA analysis, using only the hourly recorder data for timing of the rainfall. The computed maximum depths are summarized in table 1. For small areas, say less than 200 mi², the total storm duration is 12 hr or less. Because of storm movement, the duration is near 18 hr for large areas.

That the storm is indeed an unusual occurrence can be seen in figure 3. Here, Camille's rainfall (solid curves) is compared to the greatest known areal rainfalls in the United States (dashed curves) and probable maximum precipitation (Riedel et al. 1956) (dot-dashed curves) at the rainfall center. U.S. maximum areal depths are

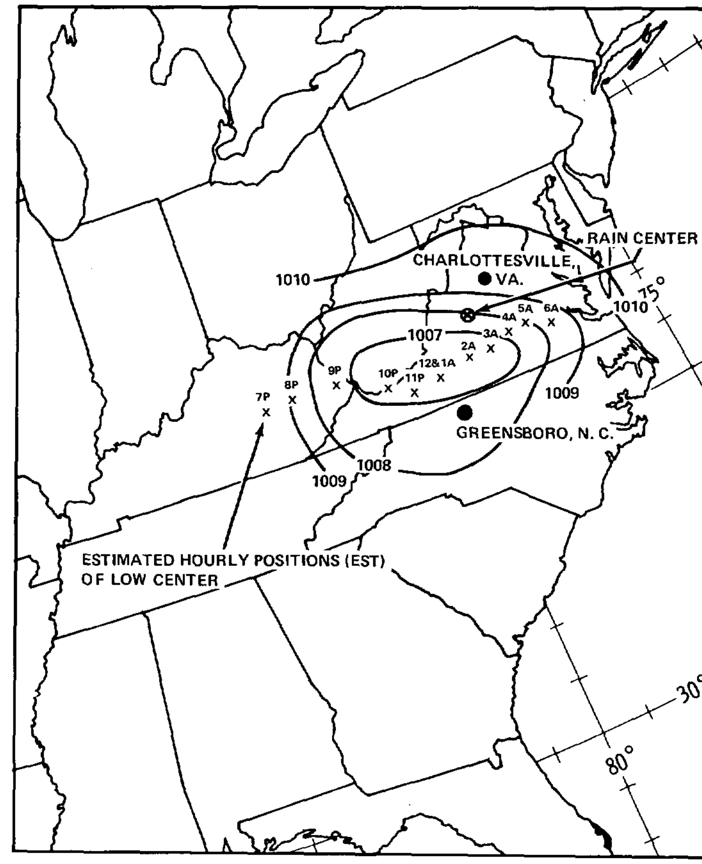

FIGURE 4.—Mean sea level pressure charts for the period 2200 to 0300 EST on Aug. 19-20, 1969.

considerably greater than those of Camille. Except for one case (the Smethport, Pa., storm of July 1942 controlling at 6 hr for 10 mi²), all the U.S. maxima are from storms in States bordering the Gulf of Mexico.

Comparision with the generalized PMP (probable maximum precipitation) values at the geographical location of the storm center shows that Camille's rainfall lies between 80 and 85 percent of estimated maximum depths for a 12-hr period for areas of 1000 mi² and less.

3. LOW-LEVEL FEATURES

Analyses of 1-hr surface charts show the circulation center of Camille passing a little to the south of the heavy rain area. Figure 4 shows both a mean sea level pressure chart near the time of heaviest rain and the estimated hourly positions of the Low center. The center apparently reformed to the east of the mountains, in Virginia, just a little south of its latitude of ingress in extreme eastern Kentucky. This track resulted in southeasterly winds, through at least several thousand feet in depth, over the area where heavy rain concentrated. At 1815 EST on August 19, the 850-mb wind at Huntington, W. Va., was from 160° at 25 mi hr^{-1}. The hourly positions of the center indicated a slowing down in the forward speed of

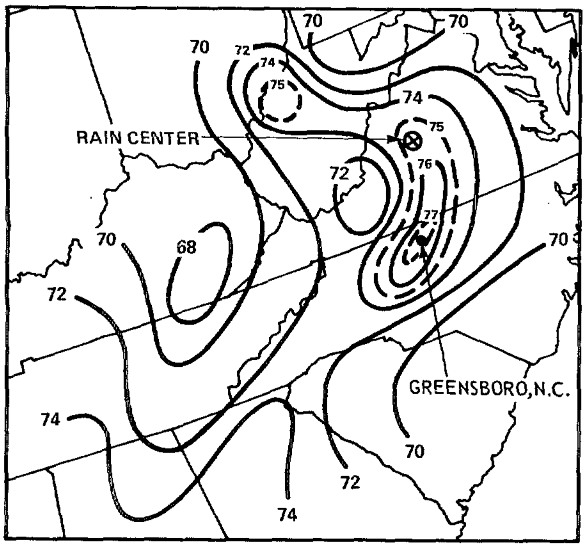

FIGURE 5.—Mean 1000-mb dew points (°F) for the period 1000 to 2200 EST on Aug. 19, 1969.

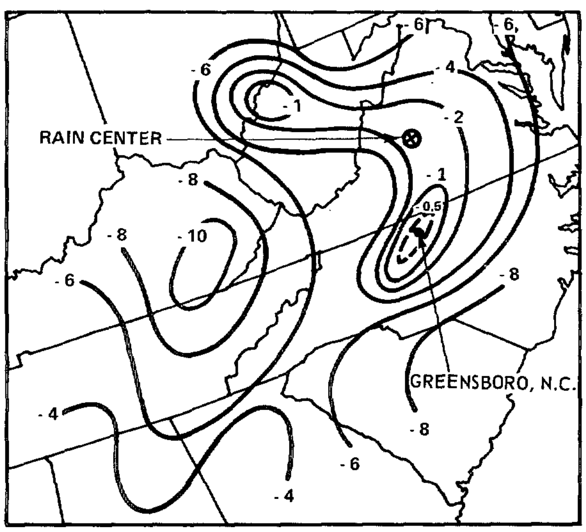

FIGURE 6.—Departure of mean storm dew points (°F) from the maximum persisting 12-hr dew points for the same season.

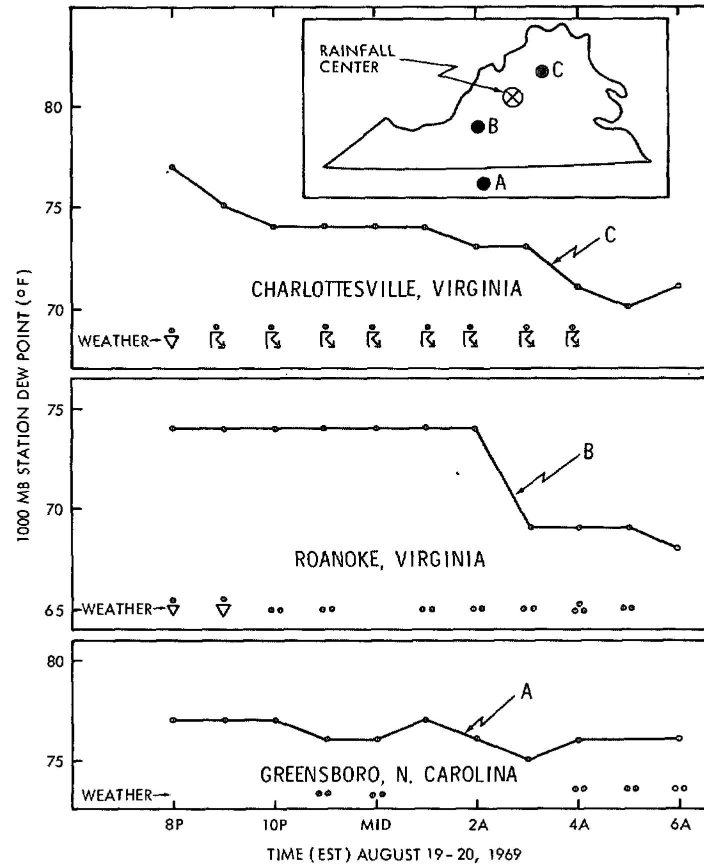

FIGURE 7.—The 1000-mb dew points and accompanying weather.

the remnant Low while passing through the area to the southwest of the area of heaviest rainfall.

An analysis of the low-level moisture field, based on surface dew points, prior to and during the rainfall shows some interesting features. Prior to the rains, low-level moisture had built to high values for the season, and this high moisture persisted in an area just upwind of the heavy rain area. Surface dew points were adjusted to a common level, 1000 mb, at the rate of 2.5°F per 1,000 ft.

Figure 5 gives a composite 1000-mb moisture (dew point) chart for the period 1000 to 2200 EST on Aug. 19, 1969. Figure 6 shows the data of figure 5 in terms of departures from maximum 12-hr persisting dew points (Environmental Data Service 1968). Noteworthy is the fact that the dew point (moisture indicator) of the air near Greensboro that was feeding into the system was just 0.5°F below the maximum values. This high moisture continued during the period of heavy rainfall.

The persistence of these high values of surface moisture near the area of heavy rain is demonstrated in figure 7. This figure shows a plot of hourly dew points and weather for Greensboro, N.C., typical of the low-level air feeding into the storm; for Roanoke, Va., near the edge of the area of more-or-less continuous rain or showers; and for Charlottesville, Va., just northeast of the heavy rain area. The 8 hr of continuous thunderstorm activity at Charlottesville is also typical of the weather in the heavy rain.

Figure 8 demonstrates the geographically fixed character of the high moisture values. Shown are successive 3-hr analyses of the 75°F and higher 1000-mb dew points for about the same period as figure 5. Such a buildup of low-level moisture to high values was found to be characteristic of a model 10-in. rainstorm (Huff and Changnon 1964).

For 14 storms in the eastern two-thirds of the United States where rains exceeded 10 in. in 6 hr, 12-hr persisting dew points averaged 72°F. In four of these cases where the rain equaled or exceeded 15 in. in 6 hr, the persisting dew points averaged 74°F.

4. UPPER AIR FEATURES

Figure 9 is an analysis of the 700-mb chart for 1900 EST on Aug. 19, 1969. This is near the time of the beginning of the heavy rain in Virginia. The east wind at Huntington indicated that a closed circulation continued to exist at the 700-mb level. The moisture values at stations around

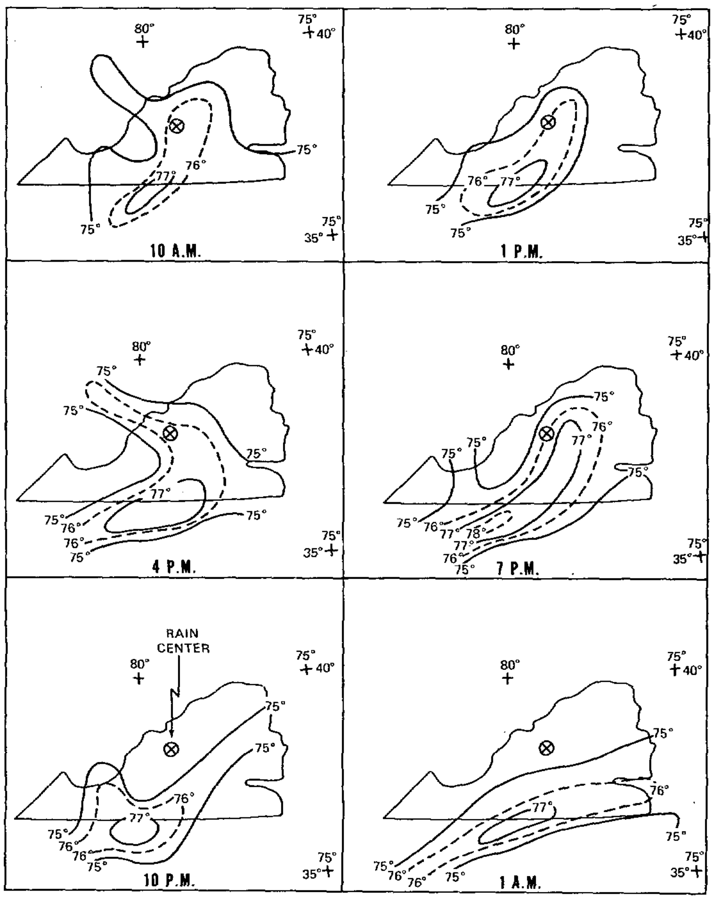

FIGURE 8.—The 3-hr analyses of 1000-mb dew points (75°F and higher), Aug. 19–20, 1969.

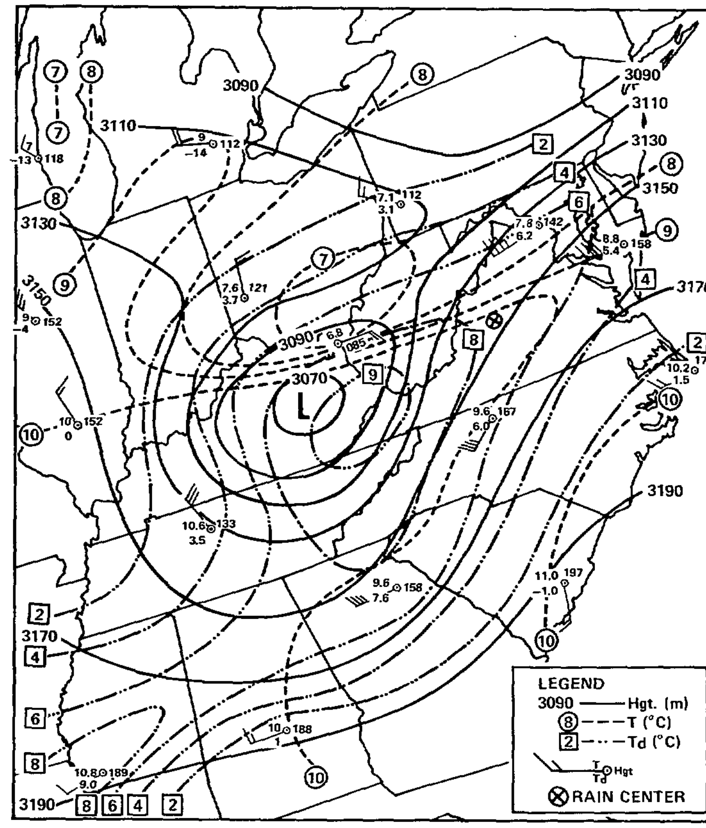

FIGURE 9.—The 700-mb chart for 1900 EST on Aug. 19, 1969.

but not too near the storm suggest that the dew points near the storm's center were about 9°C. This estimated 9°C dew point at 700 mb is 3° to 4° higher than the mean near hurricane centers (Sheets 1969). The high moisture and closed circulation are considered the most important features of the 700-mb chart.

From the latitude of Camille southward, no temperature gradient of consequence existed. To the north of the center, a weak gradient existed; although a weak gradient, this may also have contributed to the intensity of rainfall.

Analyzed charts at 500 mb and above do not show a remnant closed circulation, although it is possible a small closed circulation existed to about the 500-mb level. It is suggested that the remnants of the storm's circulation moved underneath a wind field that favored high-level divergence at the 200-mb level. This could have been significant in helping to "fix" the area of significant convective buildups (see radar discussion below) while acting as a concomitant mechanism for divergence above the concentrated lower level convergence in the area of high moisture.

5. SOUNDINGS

Several upper air soundings, jointly considered, along with moisture analysis on upper level charts provide information for estimating a hypothetical sounding that likely prevailed in or close to the heavy rain. The sounding for Greensboro, N.C., for 0700 EST on August 19 (fig. 10) shows the caliber of the low-level moisture which became poised for later injection into the remnants of Camille's circulation. Twelve hours later (fig. 11), near the time of beginning of significant rainfall, the Greensboro sounding shows changes in the direction of approximating a moist adiabatic sounding. It should be kept in mind that no tain of consequence fell at Greensboro (fig. 7) so that this sounding typifies, in the lower levels, the air feeding into rhe low-pressure system (Camille) as it moved eastward.

Figure 12 shows the sounding for Sterling, Va. (near Washington, D.C.), at a time near the beginning of the significant rain, 1900 EST on August 19. Only light rain fell in the Washington area at this time. The sounding was quite moist above 10,000 ft and relatively moist below this level. Based upon Sterling's next sounding (fig. 13) for 0700 on August 20 near the end of the rain when some cooling had occurred in low levels, it may safely be conjectured that an intermediate hypothesized sounding for Sterling would have approximated a moist adiabatic sounding with a surface dew point near 70°F. The Aug. 19, 1969, 0700 sounding for Huntington, W. Va. (fig. 14), plus the succeeding 12-hr temperature sounding (humidity element inoperative) suggest an approximation to a moist adiabatic sounding during the heavy rain, with a surface dew point similar to Sterling's.

From the above and also from standard-level moisture analyses, a sounding was hypothesized for a time approximating the middle of the rain period, about 0100 EST. This hypothesized sounding (not shown) is a moist

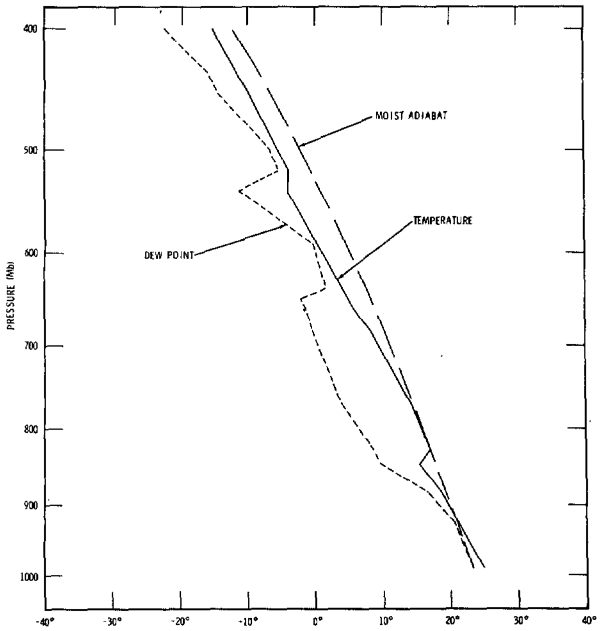

FIGURE 10.—Greensboro, N.C., sounding for 0700 EST on Aug. 19, 1969.

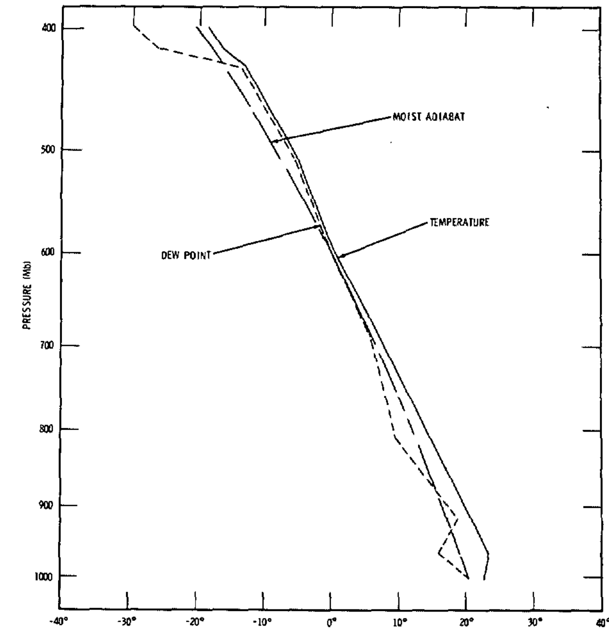

FIGURE 12.—Sterling, Va., sounding for 1900 EST on Aug. 19, 1969.

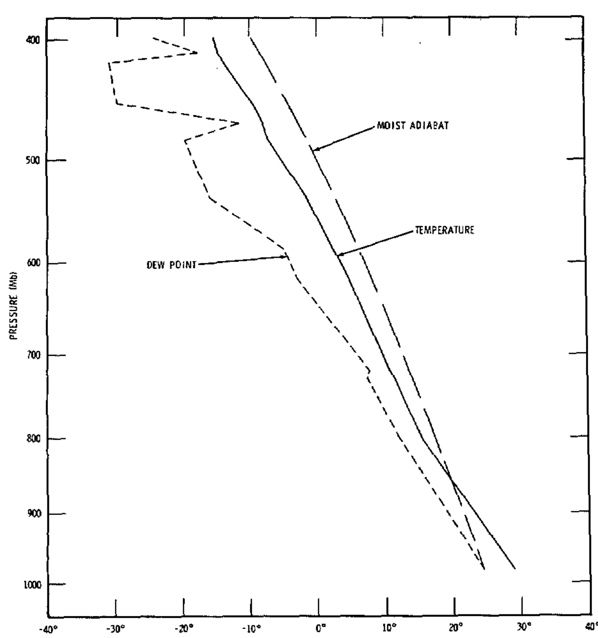

FIGURE 11.—Greensboro, N.C., sounding for 1900 EST on Aug. 19, 1969.

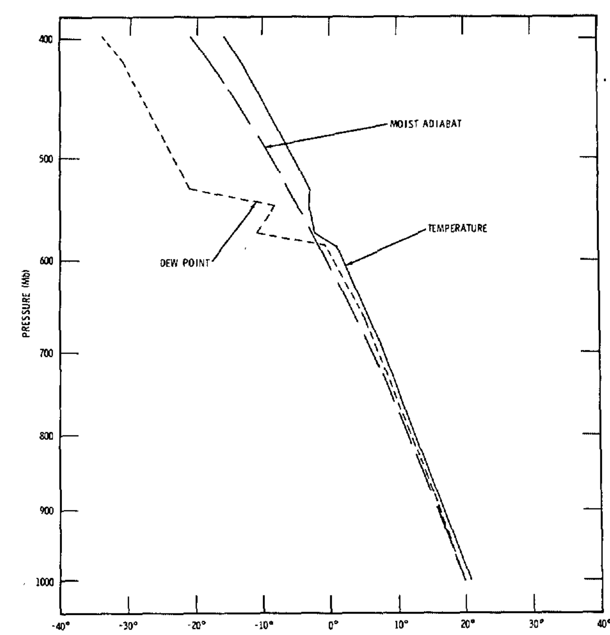

FIGURE 13.—Sterling, Va., sounding for 0700 EST on Aug. 20, 1969.

adiabatic one with a 1000-mb dew point of 76°F. to tie in with the warm moist air at low levels actually feeding into the rain area as indicated by Greensboro's soundings. The hypothetical sounding suggests air with total precipitable water of 3 in. feeding into the system.

It would be a rare occurrence for the widely spaced upper air stations to sample the true precipitable water values associated with extreme rains. Nevertheless, prior to the heavy Camille-generated Virginia rains, Camille passed about 50 mi to the west of Nashville at the time of their morning radiosonde on Aug. 19, 1969. Figure 15 compares Nashville's sounding at this time with the mean hurricane-proximity sounding (Sheets 1969). Nashville's precipitable water at the time (to 400 mb) was 2.22 in. compared to 2.07 in. for Sheets' mean sounding (fig. 15) and to 2.20 for Sheets' hurricane-proximity sounding for sea-level pressures of 1000 to 1004 mb.

A survey was made of twice-a-day precipitable water values for Nashville for the month of August for the period 1946 through 1964. This showed only one occurrence with precipitable water higher than that experienced during the passage of Camille to the west of the station. This was 2.27 in. on Aug. 2, 1956. Thus, the 2.22 in. of precipitable water observed with the close passage of Camille is an unusually high value, making the estimated 3 in.

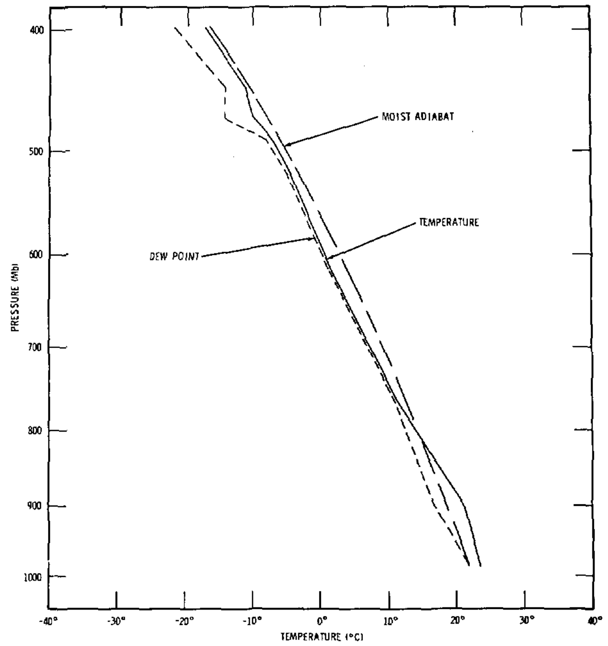

FIGURE 14.—Huntington, W. Va., sounding for 0700 EST on Aug. 19, 1969.

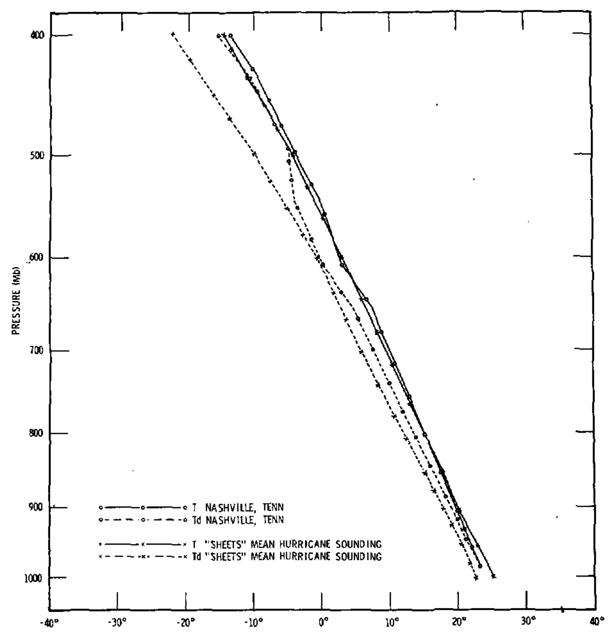

FIGURE 15.—Nashville, Tenn., sounding for 0700 EST on Aug. 19, 1969, compared to the mean hurricane sounding by Sheets (1969).

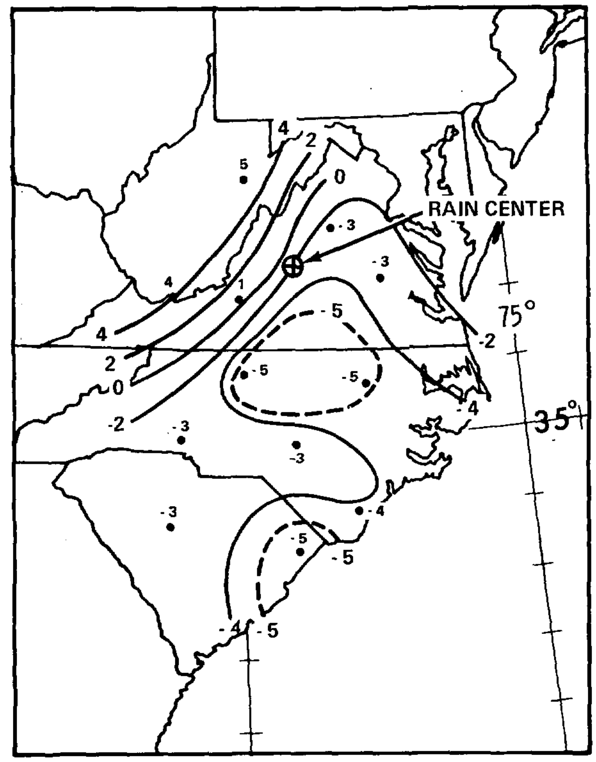

FIGURE 16.—Modified lifted index for 1900 EST on Aug. 19, 1969.

(of the hypothesized Virginia sounding) even more unusual.

6. STABILITY

For assessing the stability characteristics of the air feeding into the rain area, a modified form of the lifted index was computed. Surface observations were used along with the analyzed 500-mb temperature field. A rather sharp gradient of lifted index is suggested (fig. 16), near the area of heavy rainfall. The -5 stability index computed from surface data at Greensboro was the same as that computed for the same time using the lower 3,000 ft of moisture rather than surface conditions only.

Pronounced low-level convergence near the rain area likely contributed to a continuing destabilizing of the low-level moist airmass as it moved into the rain area during the approximately 8 hr that thunderstorm activity persisted.

7. RADAR

The rainfall center in this storm was approximately 110 n.mi. from the Washington, D.C., radar and approximately 180 n.mi. from the Pittsburgh, Pa., radar. For the distance from Pittsburgh, in general, only echoes above approximately 30,000 ft would be discernible. Echoes did begin showing on Pittsburgh's radar in the vicinity of the heavy rainfall center around 1845 EST on August 19.

Echoes within or near the heavy rain area continued to be observed throughout the night. Near 2300–2400 EST, increased echo coverage encompassed the area of heavy rains extending to 200 n.mi. and more from the Pittsburgh radar. This condition persisted for several hours.

Figures 17 through 19 show hand copies of approximately synchronous radar scope photos for Pittsburgh and Washington. The photos for each figure were taken within a span of just a few minutes so that the combined echoes can be considered as approximately simultaneous. The location of the area that experienced 10 or more inches of rain is shown as well as range markers from the respective radars.

The fact that persistent echoes existed 180 or more miles from the Pittsburgh radar appears to be quite

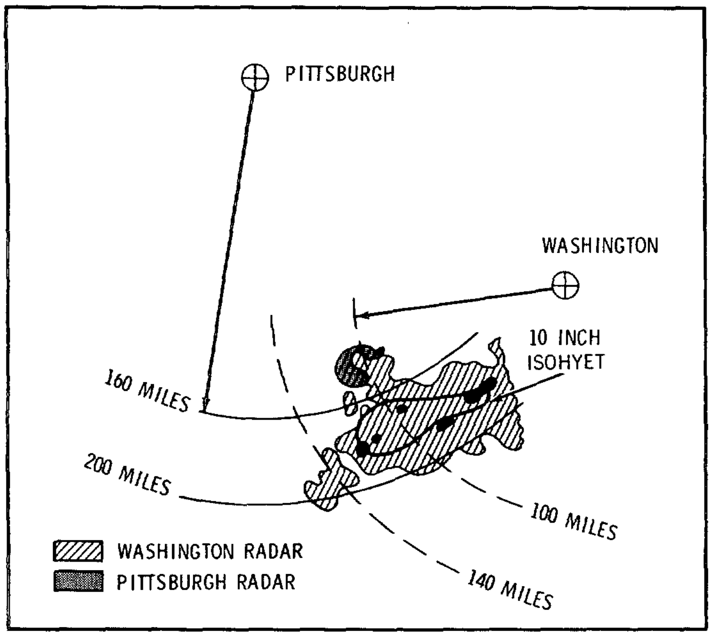

FIGURE 17.—Radar composite for 2006–2012 EST on Aug. 19, 1969.

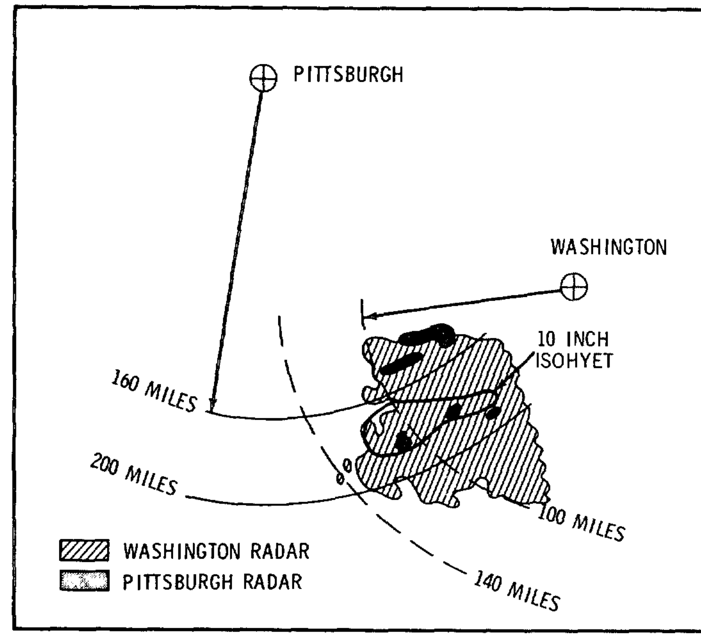

FIGURE 19.—Radar composite for 2245–2248 EST on Aug. 19, 1969.

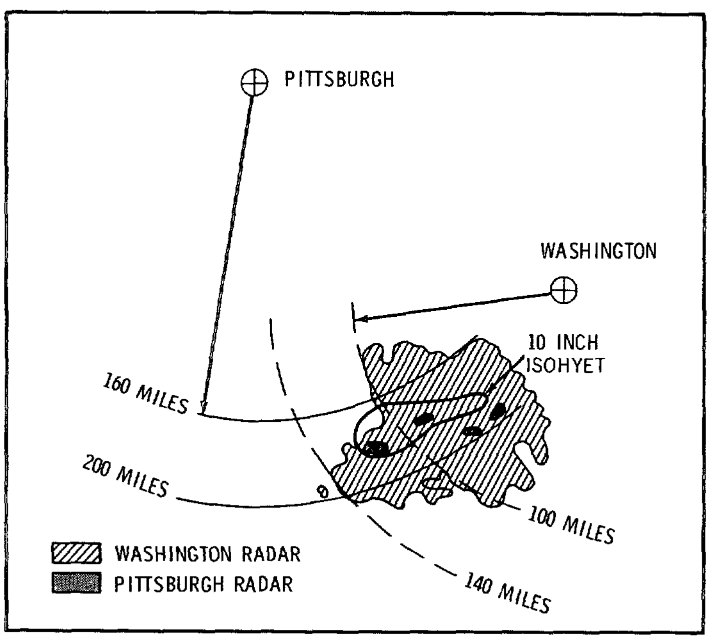

FIGURE 18.—Radar composite for 2145 EST on Aug. 19, 1969.

significant. At such a long range, barring unusual temperature stratifications, one must conclude that important vertical motion and buildup in precipitation particles existed. Thus, a rather remote radar may perform a useful function by indicating areas of important convective buildups in spite of uncertainties that exist at ranges well beyond 100 mi.

8. SATELLITE INDICATIONS

A satellite picture (fig. 20) confirms that the remnants of Camille retained more tropical storm character than one would ordinarily expect so far inland north of latitude 35° N. Ordinarily at such a location and stage (Kulawiec 1969), a dry tongue of air would have invaded the storm's circulation, signaling a "dying" stage. There was a suggestion of this happening when the storm was south of latitude 35° N. However, when over Kentucky, the evidence of this had disappeared, apparently as a result of the storm's tapping the band of extremely high moisture values that persisted to the east of the Appalachians.

For checking on the unusualness of this storm, with its long overland trajectory, a survey of all previous hurricane and tropical storm tracks was made (Cry 1965). The intent was to find any precedent for storms regaining tropical storm intensity after a long overland trajectory, particularly for storms that cross the Appalachians. No case as remarkable as that of Camille could be found. A few storms such as that of May 28–June 2, 1959, moved across the Appalachians much farther south. Two other storms, June 4–21, 1934, and Aug. 7–20, 1939, crossed the Appalachians and some portions of Virginia. None of these storms regained tropical storm characteristics.

9. CONCLUSIONS

Extreme rains, concentrating a little to the north of the track of the remnants of Camille through Virginia, were within about 80–85 percent of probable maximum values for areas up to 1,000 mi^2 for a duration of 12 hr.

A flow of air generally from the southeast in the low levels not only contributed to orographic effects on the rainfall but also made it possible for the storm to be fed by extremely high values of moisture, not subject to depletion by upwind ridges. The persisting dew points at the surface were close to maximums for the area and season.

Apparently, in addition to these high moisture values, a number of synoptic scale and mesoscale factors resulted in an efficient use of the high moisture in the form of persistent, efficient thundershowers throughout the nighttime hours. The rather remote Pittsburgh radar photos

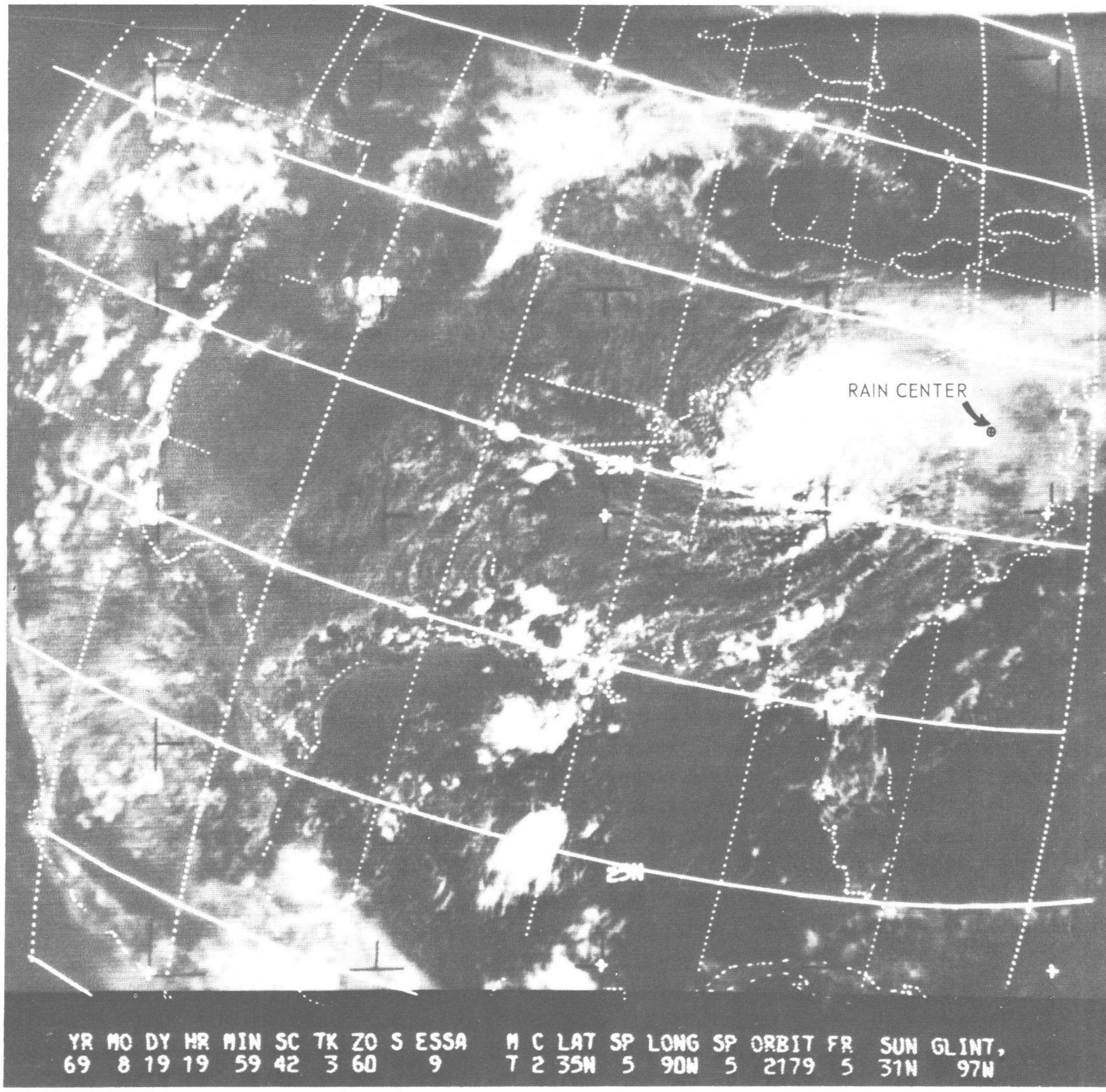

FIGURE 20.—Satellite picture of Camille for 1959 EST on Aug. 19, 1969.

indicated such a persistence of convective development to high levels.

ACKNOWLEDGMENTS

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