Some Observations of Water Contents in Hurricanes

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ABSTRACT

Liquid-water-content measurements made during the 1957 and 1958 flights by the National Hurricane Research Project airplanes have been utilized in statistical analyses to determine some of the gross features of the water distribution in hurricanes. The water contents were generally well below, and only rarely approached, the theoretical value for an adiabatic process. The analyses indicate that, in the layer from 9000 to 18,000 ft, the water contents of the convective developments decreased with height. The fraction of the storm area occupied by convective developments was found to vary with the age of the storm, being at a maximum when a storm was at its peak intensity (lowest pressure). When computed for ring areas centered on the storm center, this fraction, the "areal density" of convection, tended to decrease with increasing radius.

1. Introduction

The National Hurricane Research Project included in its comprehensive research program a study designed to increase our understanding of precipitation processes in hurricane systems. For a number of years the Cloud Physics Laboratory of the University of Chicago, under contract to the U. S. Weather Bureau, addressed itself to the multiple tasks of providing the necessary instruments for this study and of collecting and analyzing cloud physics measurements. This paper describes some of the water-content measurements obtained on flights made into tropical storms and hurricanes by the Hurricane Project B-50 airplanes during 1957 and 1958.

Cloud and precipitation processes contribute large amounts of energy to the hurricane system through the release of latent heat of condensation and provide an important means for the redistribution of energy. The energy budget is therefore intrinsically linked to the water budget, and the water budget to precipitation mechanisms. Cloud water content provides important information about both.

The water-content measurements were obtained with a paper-tape liquid-water-content meter designed by Warner and Newnham (1952) but considerably modified by members of the Cloud Physics Laboratory. This instrument measures the electrical resistance across an electrolytically treated paper tape which has been exposed to the airstream; the conductivity of the paper is a function of the amount of water it contains. A continuous record of the output of the water-content meter and of the air-speed measurements required for the concentration calculation were obtained using a Heiland Recorder. Details of the instrumentation may be found elsewhere (Braham and Nell, 1957).

From previous experience with liquid-water-content measurements it was possible to distinguish between measurements characteristic of convective clouds and those characteristic of stratiform clouds. The water measurements obtained in the convective bands in hurricanes were found to be similar, both in magnitude and variability, to those obtained in individual convective clouds of both disturbed and fair weather (Dragin, 1958; Ackerman, 1959). The water was highly variable along the line of flight, occurring in cores of a few hundred to a few thousand feet in length upon which were superimposed smaller-scale variations (Fig. 1). The smaller oscillations had periods too long to be instrumental noise but may have been due to physical noise, e.g., small random fluctuations in the droplet distribution.

![Fig. 1. An example of the water-content measurements obtained in a convective band.](image-url)
The water contents observed in stratiform clouds were, in general, a few tenths of a gram per cubic meter (much lower than in convective clouds) and fairly constant in magnitude along the line of flight. On occasion, the steady record from a layer cloud was interrupted by a small cell, usually less than one-fourth mile in length, having somewhat higher water content, perhaps up to two gm m⁻² at the peak. In rare instances, the water content had the low variability characteristic of layer clouds but the high magnitude characteristic of convective developments. These measurements were usually associated with a uniform but diffuse radar echo and may have been from dissipating convective towers or convective bands that were raining out.

Visual observations and cloud photographs indicate that the cloud distributions in hurricanes are complex, change during the life history of a storm, and may vary from storm to storm. In general, however, well-spaced convective cloud bands or lines are embedded in widespread stratiform clouds occurring at several levels. The water-content measurements reflected this cloud distribution. Sections of convective-type measurements covering one to five miles of airplane traverse distance periodically interrupted long periods over which the water content maintained the low, steady value characteristic of the layer-type cloud. Sometimes the convective cells would occur in groups as the airplane flew through the several clouds composing a band.

The data discussed herein were collected on five flights through four storms. All but one of the flights were into hurricanes; Tropical Storm Becky, which was penetrated on flight 80813B, never attained hurricane intensity. Some pertinent information about the storms and the flights is given in Table 1; additional details are available from other sources (e.g., Moore et al., 1957; Stoff, 1958). The portions of airplane paths over which water measurements were collected are shown in Fig. 2; the heavy bars identify the sections where the measurements were of the convective-type. In order to provide a very general picture of the cloud structure in the storm, the echoes detected by the airplane’s radar at two or three times during the flight also are shown. The differences between the locations of the radar bands and the convective-type water measurements are a mani-

<table>
<thead>
<tr>
<th>Number</th>
<th>Flight</th>
<th>Alt. (ft)</th>
<th>Temp. (C)</th>
<th>Central sfc. P.</th>
<th>Stage</th>
<th>Movement</th>
<th>Eye structure</th>
<th>Clouds and hydrometeors</th>
</tr>
</thead>
<tbody>
<tr>
<td>70915B</td>
<td>Carrie</td>
<td>9/15/57</td>
<td>18,000</td>
<td>+2 to -3</td>
<td>960 mb</td>
<td>Filling slowly</td>
<td>300°12 kn</td>
<td>Well defined, 40 n mi in diameter</td>
</tr>
<tr>
<td>80813B</td>
<td>Becky</td>
<td>8/13/58</td>
<td>15,600</td>
<td>+2 to -4</td>
<td>1006 mb</td>
<td>Mature</td>
<td>290°21 kn</td>
<td>Not defined</td>
</tr>
<tr>
<td>80825B</td>
<td>Daisy</td>
<td>8/25/58</td>
<td>15,600</td>
<td>+6 to -3</td>
<td>992 mb</td>
<td>Intensifying rapidly</td>
<td>340°7 kn</td>
<td>Fairly well defined, 15–20 n mi in diameter</td>
</tr>
<tr>
<td>80827B</td>
<td>Daisy</td>
<td>8/27/58</td>
<td>13,000</td>
<td>+3 to +7</td>
<td>950 mb</td>
<td>Near lowest pressure</td>
<td>025°8 kn</td>
<td>Well defined, 10 n mi in diameter</td>
</tr>
<tr>
<td>80924B</td>
<td>Helene</td>
<td>9/24/58</td>
<td>13,000</td>
<td>+1 to +7</td>
<td>997 mb</td>
<td>Young, intensifying</td>
<td>320°10 kn</td>
<td>Fairly well defined, 20 n mi in diameter</td>
</tr>
</tbody>
</table>
Fig. 2. Location of the water-content measurements. Convective-type water contents are indicated by heavy bars. The radar echoes are those detected by the airborne radar at the time specified.
festation of the transient nature of the cloud systems.

The storms studied differed considerably in their intensity and history. Tropical Storm Becky reached its lowest central surface pressure (1006 mb) on 12 August 1958 and changed little for two or three days thereafter. During flight 80813B into this storm, the flow and cloud fields were poorly defined and the location of the storm center was uncertain. There were a few cloud lines: one extending nearly 100 mi in length moved 70 to 80 mi east during the period of the flight. Most of the heavy water was encountered in this band.

Hurricane Carrie was at its most intense (with central pressure of 945 mb) on 12 September 1957. However, it filled slowly and still had a well-defined eye and low central pressure (960 mb) on 15 September when flight 70915B was made. The flight pattern was to have been a cloverleaf but shortly after the first penetration of the hurricane eye the airplane developed engine trouble and the flight had to be terminated. As a result only limited data are available, the bulk of it collected close to the center of the storm.

Flight 80825B was made into Hurricane Daisy on 25 August 1958 shortly after the storm had reached hurricane intensity and during a period of very rapid intensification. The lowest central surface pressure (935 mb) occurred two days later, a few hours after flight 80827B was completed. A cloverleaf flight pattern was followed on the earlier flight, with additional maneuvers made through a band in the northeast quadrant in connection with a seeder experiment. A cloverleaf was followed on the 27th also; however exceedingly heavy water encountered on the first penetration through the wall clouds east of the eye saturated the paper tape of the water meter and caused it to tear. Therefore, only limited data are available and the sample may contain some bias both because of the limited area probed and because so much of it (12 per cent of the observations) was obtained in the exceptionally heavy water of the eastern wall cloud.

Hurricane Helene, still a very young storm on 24 September 1958 when flight 80924B was made, was intensifying at a steady though moderate rate and reached its minimum surface pressure (933 mb) on the 27th. Entry into the storm was made at 9000 ft but most of the data were collected at 13,000 ft on a cloverleaf flight pattern. Data were collected only in the southwest quadrant at 9000 ft; fairly comprehensive coverage was attained at the upper altitude.

2. Analysis

The methods used in any analysis and the interpretation of results are largely dictated by the basic nature of the parameter under study. Liquid-water content is a discontinuous variable—it exists only where a cloud exists. It has great spatial variability; order of magnitude differences have been observed between different areas in a single tropical cumulus as well as between individual tropical cumuli (Ackerman, 1959). It has large temporal variability arising from the movement of the cloud systems and the short time scale of the cloud and precipitation processes. Jordan (1960) has observed individual cloud units in a convective band moving roughly with the speed of the winds. Senn and Hiser (1959, 1960) have estimated the durations of these units to be between 10 and 45 minutes, and the lifespan of a band as a whole to be of the order of a couple of hours.

In addition, the measurements under consideration were obtained at several different altitudes from storms at varying stages of their life history. The hurricane cloud systems and their water contents may change both with the stage of the storm and with altitude so that these factors too must be considered in the analysis and interpretation of the data.

The areal extent of the hurricane system, the low areal density of the convective cores and the transient nature of the clouds all give rise to difficulties in the interpretation of the water measurements. Since the measurements were collected from a single moving platform, they represent only a small fraction of the total area and include both the spatial and temporal variations. As a consequence a synoptic-type analysis in which steady state is implicitly assumed is not possible and any spatial comparisons must be made with care.

Other hurricane research studies indicate that changes in the general flow pattern are so slow that the gross features of the water distribution in the storm as a whole probably do not change too much in the few hours covered by a flight (though this may not be true of the details of the areal array). Therefore steady state was assumed for the liquid-water content of the storm as a whole and a statistical approach was employed to determine the gross characteristics of the liquid water. Since data were collected on a pre-conceived flight plan independent of the individual storm characteristics the samples are believed to be representative, with perhaps one exception. As has already been mentioned, the data collected on flight 80827B into Hurricane Daisy may not be too representative of the storm both because of the limited area in which they were collected and because so much of the sample was obtained in the very wet clouds of the eye wall.

Several problems were considered: a) what are the general characteristics of the water content in hurricanes, particularly in the regions of convective developments; b) does the water content vary with the age of the storm; c) does it differ at different altitudes and d) does it differ with quadrant or with distance from storm center. Frequency distributions and their characteristic values were used to describe the storm water.

The measurements were recorded continuously with

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2 A descriptive study of individual storms has been summarized in a report to the Weather Bureau (Ackerman, 1962).
recorder-paper speed of approximately one centimeter per second. Although the resolutions of the measuring and recording systems were approximately one-tenth of a second, the data were reduced in the form of average values over one-second intervals (roughly 350–400 ft at the speed of the airplane). The use of a standard interval was predicated on the necessity for uniformity in the sample populations and also on the need for a unit of measurement which, in view of the large amount of data involved, would permit easy handling. The choice of one second was somewhat arbitrary; however it served to filter out some of the smallest-scale fluctuations without masking the cell-size changes.

The measurements are believed to be reliable except at very low water contents. The instrument has low sensitivity at water contents below about 0.1 gm m⁻³ and it was not always possible to distinguish between clouds of very low-water content and clear air. Therefore all the observations, whether they had been made in clear or cloud air, were used in the determination of the percentage frequencies.

Some of the flights were made in the vicinity of the freezing level. However ambient temperatures were almost always warmer than −3°C and there probably was no serious icing. On occasion solid precipitation was encountered; this solid portion of the realized water was not measured.

In examining the data with respect to storm stage and altitude, the water contents (W) were expressed as fractions of the theoretical adiabatic water content (Wₐ), i.e., the amount of water realized in parcel ascent from cloud base to measurement altitude, with no dilution or rainout. In computing Wₐ, it was assumed that all cloud air originated in the sub-cloud layer and reached saturation at the height of the bases of the cumulus clouds. This assumption is, of course, a poor one for the stratiform clouds but since these occurred at several levels and though extensive, were not in continuous layers a representative base height could not be established. The mean hurricane soundings published by Jordan (1958) and the base heights of the cumulus and cumulonimbus clouds reported by Navy reconnaissance planes were used in making the calculations. The computed values of Wₐ are shown in Table 2.

### Table 2. Characteristic values of the frequency distributions of water contents (W) in the total storm area and in convective regions.
All water contents given in gm m⁻³. Wₐ = adiabatic water content; N = number of observations.

<table>
<thead>
<tr>
<th>Flight</th>
<th>Altitude (ft)</th>
<th>Wₐ</th>
<th>All measurements</th>
<th>Convective-type measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>N*</td>
<td>N*</td>
</tr>
<tr>
<td>70915B</td>
<td>18,000</td>
<td>7.6</td>
<td>1770</td>
<td>264</td>
</tr>
<tr>
<td>80813B</td>
<td>15,600</td>
<td>7.2</td>
<td>8734</td>
<td>597</td>
</tr>
<tr>
<td>80825B</td>
<td>15,600</td>
<td>7.3</td>
<td>11394</td>
<td>1805</td>
</tr>
<tr>
<td>80827B</td>
<td>13,000</td>
<td>6.5</td>
<td>1880</td>
<td>347</td>
</tr>
<tr>
<td>80924B</td>
<td>13,000</td>
<td>6.7</td>
<td>7520</td>
<td>983</td>
</tr>
<tr>
<td>80924B</td>
<td>9,000</td>
<td>5.9</td>
<td>876</td>
<td>81</td>
</tr>
</tbody>
</table>

* All observations—including those in clear air.
13,000 ft (curve 5); flights 80813B and 80825B (curves 1 and 3) were made at 15,600 ft; flight 70915B (curve 2) was made at 18,000 ft. The frequency distributions shift consistently toward lower relative water contents ($W/W_a$) with altitude. Moreover the upper quartile values for the convective areas (Table 2) indicate that, above 9000 ft, the absolute water contents of convective bands, as well as the relative water contents, decreased with height.

The water contents encountered in the convective areas of Hurricane Daisy on flight 80827B were higher than those found on any other flight. This was very likely due, at least in part, to bias in the sample. However if the data collected in the wall cloud (the wettest part of the flight) are omitted, the median and upper quartile values of the resultant frequency distribution are 0.78 and 1.49 gm m$^{-3}$, respectively, considerably higher than like values for data collected at the same altitude on flight 80924B. An obvious difference between the two flights is that flight 80827B was made into Hurricane Daisy when it was very near its lowest surface pressure while flight 80924B was made into a young, intensifying Hurricane Helene. The data therefore suggest that the water contents of convective clouds may be somewhat lower during the developing stages of a storm than when the storm has matured and is at its peak.

Variation of water content with location in storm. In this phase of the study the data were re-examined for asymmetries and for variations with distance from the center of the storm. For the first of these analyses the storm region was divided into quadrants using the pair of lines lying at 45 deg to the direction of storm movement. The frequency distributions for each quadrant is plotted, by storm in Fig. 4. (Distributions for flights 80827B and the 9000 ft level on 80924B are not shown because all of the data were collected in one or two quadrants.)

It is obvious from the frequency distributions that some asymmetries do exist, e.g., the observations from Hurricane Daisy on 25 August suggest that the water content was greater in the right and rear quadrants than it was in the front and left quadrants. However, these asymmetries differ from storm to storm and appear to be characteristic of an individual storm. It should however be noted that the water contents were higher in the rear quadrants than in the front quadrants in the two intensifying storms (flights 80825B and 80924B) whereas the reverse was true in the one flight (70915B) through a filling storm.

In studying the variation of water content with distance from storm center the area was divided into concentric rings, all but one of which were 20 mi in width. The one exception was the inner ring which was defined by the inner boundary of the wall cloud and the 20-mi range line. Because the area so defined is largely filled with wall cloud, the resulting sample may be biased toward high water content. The cumulative-frequency distributions for these rings are shown in Fig. 5. In order to reduce the number of curves in the individual graphs, two adjacent annuli were combined on occasion, but only if their individual distributions were similar or consistent with the trend.

For the organized hurricanes the frequency curves shift consistently to lower water contents with increasing distance from center. Only the data for flight 80813B into Tropical Storm Becky do not show this trend. However, the circulation and cloud patterns during this flight were poorly organized and there was no real orientation of the clouds around the center. An examina-

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**Fig. 3.** The ogives of the frequency distributions of all water-content measurements (upper) and of water-content measurements of convective-types only (lower). Frequencies are expressed as the percentage of measurements which were equal to or greater than the values along the abscissa.
Areal density of convective clouds. The relative frequency of convective-type water contents gives a rough estimate of the areal density of convective developments, and through the remainder of this report will frequently be referred to as such. However the reader should bear in mind that these are relatively crude estimates, the reliability of which is dependent on involved sampling problems.

In order to gain added information the records from five additional flights made in 1958 were scanned and the relative frequency of convective-type water measurements calculated. Some pertinent information about these flights are given in Table 3.

The relative frequency of convective-type water for the storm as a whole (columns 4 and 5 of Table 4) varied considerably from flight to flight—from a few per cent to nearly 50 per cent. It is evident from these data that the areal density of convection changes as the storm passes through the various stages of its life. For the
Fig. 5. The ogives of the frequency distributions of the water contents measured in concentric rings (see text). Frequencies are given as the percentage of all observations in a given annulus having water contents equal to or greater than the value along the abscissa.
region within 60 mi from the center, around 20 per cent of the measurements were of the convective type in young, deepening storms, increasing to 30 to 40 per cent for storms near peak intensity and then decreasing again for filling storms to around 20 per cent within about three days after peak intensity. The areal density of convection in tropical storms were just a few per cent—much lower than in hurricanes.

In the right hand portion of Table 4 is given the relative frequency of convection as a function of distance from storm center. In most cases the samples for the annular rings are so small that it is difficult to draw conclusions. However considering those flights for which there are the most data, it appears that, at least during intensifying and mature periods, the areal density of convection in hurricanes tends to decrease outward from center, and that this decrease is such that the total area involved in convective clouds at the middle levels also decreases outward. The data from flight 80818B suggest that this trend may start breaking down as a storm fills. In tropical storms on the other hand, there does not appear to be any systematic change in the areal density of convection with distance from the storm center.

The areal density of convection for the various quadrants for a limited number of flights are given in Table 5. As was concluded from the frequency distributions, some asymmetries do exist but appear to be characteristic of individual storms.
4. Discussion

The water contents of the hurricane cloud systems were found to be highly variable—with variations of sizes similar to those previously reported for cumulus of less severe weather. Because of the discontinuous and transient nature of the cloud water and the large areal extent of the hurricane, even the large volume of data which has been utilized in this study represents a relatively small sample of the total population. Nevertheless certain gross features of the water contents of hurricane cloud systems are revealed in the statistical values derived in the analysis.

The liquid-water contents were seldom over three or four gm m\(^{-3}\) and the bulk of the measurements fell below one gm m\(^{-3}\). Water contents consistent with undiluted adiabatic ascent were rarely found; almost all of the measurements were less than 50 per cent of the theoretical adiabatic value. Not surprisingly, the heavier water contents were found in convective clouds and cloud bands. However even in these developments the amount of water was usually well below the adiabatic value.

Deviation from the theoretical adiabatic model is not unusual and may come about for a number of reasons. Perhaps the most important are dilution due to mixing with the environment and sedimentation and storage in precipitation. In addition, in areas with sub-zero temperatures some of the realized water may be in the solid phase, which was not measured on these hurricane flights. This may have been a factor in the reduction of liquid-water content on the flights made close to the freezing level. However, although solid hydrometeors were occasionally reported, the temperatures were almost always warmer than \(-5^\circ C\) and it is doubtful that much of the realized water was in the solid phase except where snow and rain were falling from above. In these cases sedimentation (rainout and storage) probably has much greater overall effect than does freezing.

The effectiveness of mixing in reducing the water content of convective clouds depends on the magnitude of the mixing and the humidity of the environment. Hurricane air is frequently assumed to be at or very near saturation throughout; measurements made by the National Hurricane Research Project suggest that the humidity is seldom less than 90 per cent. The evaporative effects of mixing will therefore be limited. There is however the possibility of sizeable redistribution of the liquid water in the mixing process—with the realized water being shared by the admixed and originating cloud air. Just how this redistribution may occur is a matter of conjecture; it will depend to great extent on the mechanisms by which entrainment and mixing take place. These processes are still a matter of considerable debate and study. However, a redistribution of liquid water in the mixing process may be a factor in the establishment and/or maintenance of the widespread cloud decks so commonly found in hurricanes.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{fig6.png}
\caption{Fig. 6. The vertical variation of the water contents in hurricane convection (curve 4) and in cumuliform clouds of less severe weather reported in other investigations (curves 1--3).}
\end{figure}

Both the absolute water content \((W)\) and the relative water content \((W/W_o)\) decreased with height (over the range of 9000 to 18,000 ft) in the regions of convection. Systematic decreases of relative water content with height have been observed in smaller, less complex convective cloud systems (Warner, 1955; Squires, 1958; Dragnins, 1958; Ackerman, 1959). The mean vertical variations reported by Warner and Squires for isolated maritime and landward cumuli in Australia and by Ackerman for small and medium sized cumuli over the subtropical Atlantic are shown in Fig. 6, along with those found in the hurricane convective clouds and bands. (The Warner data are for the peak \(W/W_o\) on a cloud pass averaged over all cloud passes; the Squires’ data are for the median values at an altitude; the other two curves are the averages of the mean relative water contents for the entire traverse through the cloud or convective band.)

The hurricane curve may be extrapolated to join with curve 3, drawn for data from smaller clouds in the same geographical region under conditions of fair or mildly disturbed weather. (Such a curve nearly parallels the Squires curve.) There are some cogent arguments against (and also for) such a simple joining of the two curves. However available evidence indicates that the basic features of convective clouds are remarkably
similar for a wide range of weather conditions and geographical locations and it is felt that a reasonably accurate mean picture of the vertical distribution of water content in hurricane cloud systems is obtained by an extrapolation of the data from hurricanes to the lower altitudes, using the other curves as guides to determine the shape. Such a mean picture indicates a net loss of water from the upper to the lower layers in the hurricane, which is to be expected in rain clouds. However the degree to which the observed water contents were below the theoretical value suggests that a considerable portion of the water released in active convection may, through the mixing process, go toward modifying the environment in the middle and lower layers.

There is some evidence of asymmetry in the distribution of water content but because of the variability of water content and the relatively small samples, it was difficult to establish whether these were systematic or, as one must conclude from the available data, characteristic of individual storms. The data did suggest, however, a decrease in water with increasing distance from the center of the storm. This trend, as well as the asymmetries, appear to be associated with variations in the areal density of convection rather than with true differences in the water contents of the clouds themselves.

The areal density of convective developments (defined as the fraction of the observations having convective-type water content variations) varied with the stage of storm development. For the inner rain area (radius<60 n mi), it increased from about 15 to 20 per cent in the young, deepening storm to 30 to 40 per cent in storms near their peak intensity, and then decreased again for filling storms.

Malkus et al. (1961) have estimated the areal density of penetrative “hot tower” convection (cloud towers exceeding 37,000 ft) in Hurricane Daisy to have been 1 per cent of the area within 200 n mi of the storm center on the formative day (25 August) and about 4 per cent on 27 August, the most active day. The areal density of convection at the middle level (15,600 ft) in Hurricane Daisy on 25 August, as determined from the water measurements, was 23 per cent for the area within 60 mi of the center of the storm and about 16 per cent for the inner 100 mi. Making use of the observed decrease of the incidence of convective occurrences outward from the center, the areal density of convection within 200 miles, at the middle levels, is estimated to be about 2 per cent—twice that reported by Malkus. This suggests that approximately half the convective area at middle altitudes is sufficiently active to penetrate through the 35,000 ft level. On the basis of a crude estimate of the root mean square diameter of the convective cells, it would appear that perhaps one cell out of about six occurring at the 16,000 ft level might be expected to reach heights of about 35,000 ft.

The water-content data for 27 August in Hurricane Daisy are extremely limited. Making use of the measurements made in Hurricane Helene on its most active day (flight 80926B) the areal density of convection at middle levels is estimated to be about 4.5 to 5 per cent (certainly no more than 6 per cent) for a storm at its peak. Comparing this value to the 4 per cent cited by Malkus for penetrative convection suggests that in the most intense stages of a hurricane, a relatively larger fraction of the convective region is of the so-called penetrative intensity.

The difficulties encountered in observational studies of convective clouds due to natural variability are compounded in hurricanes because of the large area involved and the changes occurring in the storm itself. The need for reliable measurements of the physical-chemical nature of the hurricane air, both cloudy and clear, is an ever present one. Thorough understanding of the cloud processes and their contributions to the energy of the total storm requires much additional study in which the interplay of the convective clouds and their immediate environment should not be ignored.

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REFERENCES


