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SECOND AUTUMN WORKSHOP ON
CLOUD PHYSICS AND CLIMATE

(23 November - 18 December 1987)

A DIAGNOSTIC STUDY OF CLOUD DISTRIBUTION AND DEVELOPMENT IN HURRICANE DEBBIE AUGUST 13-19,1969 FROM SATELLITE DATA

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APPENDIX 2

Tellus (1977), *29*, 402–414

A diagnostic study of cloud distribution and development in hurricane Debbie August 13–19, 1969 from satellite data

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(Manuscript received May 17; in final form November 23, 1976)

ABSTRACT

A diagnostic study of cloud distribution and development in hurricane Debbie August 13–19, 1969 using satellite data and based on a photometric method described earlier by Balogun (1976) is presented. A systematic assessment of the cloudiness of a tropical cyclone over the oceans by a method that is less sensitive to personal bias demonstrates the following features of the cyclone:

(1) The gradual changes in the cloud patterns of a tropical cyclone. The changes take place in a definite manner.

(2) The non-axis symmetric nature of the tropical cyclone cloud pattern. The lack of symmetry at the early stages of the cyclone is quantified. The parameter obtained is then used to demonstrate the process of symmetricalization at the latter stages of the cyclone.

(3) The rate of rotation of the cloud bands about a central axis of the cyclone is less than the rate of rotation of air parcels about the axis of rotation. The rate of rotation of the bands is estimated to be about 50–75% of the rotation of air parcels. This estimate was for a period of about 7 h during the lifetime of the cyclone. The lower rate of motion of the bands suggests that the field of the low level convergence moves at a different rate from the air parcels about the axis of the cyclone.

1. Introduction

Hurricane Debbie was one of the North Atlantic hurricanes of the hurricane season of 1969. The cyclone was identified as a tropical disturbance on August 13, 1969 and as a tropical storm at 1200Z on the 15th. The storm intensified slowly as it moved NNW and became a hurricane at about 1800Z on the 16th. It then moved NW while its maximum wind speeds increased to 90 kts. It was at its peak strength on the 20th with a centre pressure of 950 mbs. Its winds dropped below hurricane force late on the 24th and by the 25th the cyclone, then with a central pressure of 988 mbs, was identified as an extra-tropical cyclone.

In this study the daily cloud patterns of the cyclone were studied from August 13–19, 1969. The period thus covered the formative and development stages of the cyclone. Fig. 1 shows the path of the cyclone.

The method used in estimating cloud cover over Debbie was that described by Balogum (1977). The method involved using a photometer to estimate the whiteness of the photographs by illuminating the back of carefully prepared photographs of tropical cyclones on a special nonstretching photographic paper, and recording the transmitted light. The transmitted light was then converted to "cloud amounts". After estimating the cloud amounts within one-degree squares over the area of the tropical cyclone, concentric circles of radii 1°, 2° ... 9° latitude were drawn on the photographs with the observed or estimated centre of the storm as centre. From the same centre, radial lines were drawn at an azimuthal interval of 10° so that the radial lines intersected each circle at 36 equally spaced points. All azimuthal distances were measured from the North. A weighted estimate of the satellite-observed cloud cover was then determined at each of the 36 points along each circle. Each value was referred to as the satellite-observed cloud cover estimate and was denoted by *N*. That quantity was the basic data used for studying the distribution and development of

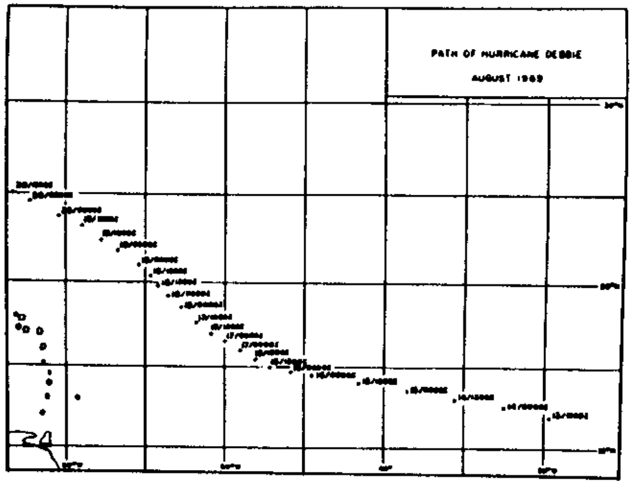


Fig. 1. Path of hurricane Debbie; August 13–August 20, 1969.

clouds of the tropical cyclone as observed by satellites.

Using the values obtained for each of the 36 points on each circle, a harmonic analysis of the cloud cover estimates was carried out. The amplitudes and phase angles of the dominant harmonic components obtained from the analysis were then used to describe the cloud patterns.

2. Some previous studies on satellite-observed cloud structures of tropical cyclones

Earlier studies of tropical cyclones using visible imagery of the cyclones as obtained from satellites dealt essentially with qualitative pattern recognition of the different stages of tropical cyclones. From these studies some useful knowledge about the cyclone development and growth was obtained. With the earlier work by Fritz (1964), Frank (1963) and Erickson (1963) which described the cloud features associated with the early development of tropical cyclones as background, some researchers a few years later suggested various models of tropical cyclone development as deduced from associated cloud patterns. Fett (1964, 1968a, b) has suggested one of such models in his earlier paper. He suggested that the development of the cloud patterns associated with the development of the tropical cyclone could be sub-divided into four stages ranging from elongated cloud mass along the axis of some tropical wave systems to a well-developed cirrus shield over the mature cyclone. He improved on those models in his later paper. Fritz (1964) and Fritz et al. (1966) have also presented satellite-derived models of cyclone development. Oliver (1969) presented a scheme of classification of tropical cyclones that combines some of these earlier models. The scheme classified tropical vortex cloud systems into four groups in which the basic descriptive parameters were size and position of associated overcast areas, the degree of circularity of the spiral band structure and the location of the centre with respect to the major cloud mass of the cyclone. Other schemes have been presented by Dvorak (1972). Some of these schemes permitted the estimation of maximum winds in the tropical cyclone systems.

Apart from using the visible imageries of tropical cyclones, digital products of High Resolution Infrared radiation data had been used (Hubert et al., 1969). In that paper, two features of the radiation patterns of the cyclone were used to indicate the intensities of cyclones. These were the inner radius associated with the cyclone's eyes r_i and an overall canopy size, r_o. The ratio of these parameters had been used to estimate maximum wind speeds in tropical cyclones. That paper suggested that methods used in the analysis of photographic methods may also apply to infrared storm patterns. The prospects of using infrared data are examined in a later section of this paper.

In this paper, a technique developed by the author Balogun (1977) is applied to the visible imagery of hurricane Debbie. The technique permitted the pattern of the cloud distribution in the cyclone to be studied quantitatively at different stages of its development. The analysis points to the orderly, even though complex development of cloud pattern within the hurricane system. The present paper deals essentially with the way satellite-observed cloud is distributed, and how the observed bands are oriented in a tropical cyclone of the North Atlantic. Further analysis of other tropical cyclones, applying the same technique to other data—preferably infrared radiation data—may enable an improved classification of the tropical cyclone systems to be presented.

3. Parameters for the description of the cloud patterns

The various parameters by which the cloud cover over hurricanes could be described using the photometric method have been discussed by Balogun (1977). The distribution of cloud cover estimates N (measured in tenths) and the orientation of the cloud patterns are quantitatively described by parameters r_N, a_r, and also by the phase angles of the harmonic components considered. The parameter r_N is defined as the radial distance from the centre of the cyclone at which a value N of the estimated cloud cover is most frequent. The quantity r_N for a particular cloud cover value N, changes from one cloud pattern to another. The parameter therefore provides an objective means of studying the changes in areal extent of cloud cover in tropical cyclones as the cyclones develop.

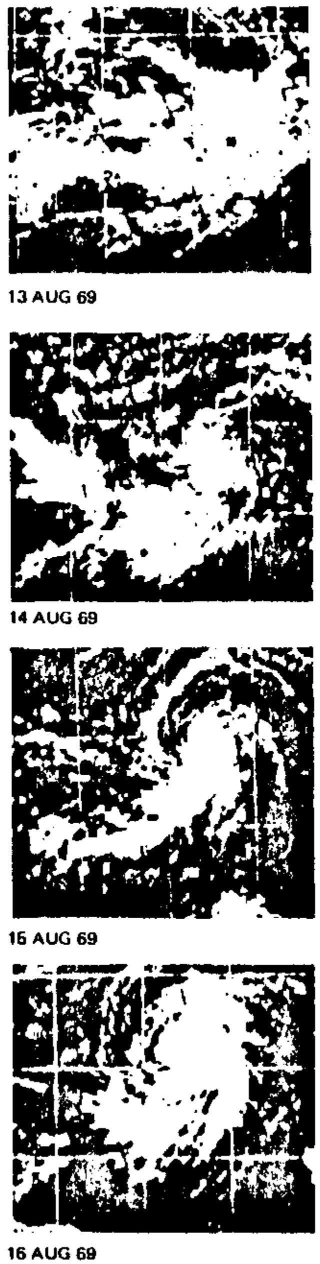
The quantity a_r is a measure of the asymmetric distribution (non-circumferential distribution) of the cloud cover estimates about the centre of the cyclone. It is the normalized amplitude of the first harmonic component. This quantity plotted as a function of radial distance for each cloud pattern shows maximum values near the centre of the cyclones at the early stages of the cyclone. As the cyclone matures the position of the maximum value of the parameter should be located farther away from the centre of the cyclone. The higher the value of a_r the more asymmetric the pattern. The curves joining the phase positions along each of the nine circles for the first two harmonic components for each pattern are identified as phase curves and are used to study the changes in the orientation of the cloud patterns during the course of development of the cyclones.

4. Analysis of the daily ESSA photographs of hurricane Debbie

The ESSA satellites (environmental survey satellites) were launched into a near polar sun-synchronous orbit so that the orbital plane rotated about the earth at exactly the same rate as the earth orbits the sun. The orbits of the satellites were at altitudes of about 1400–1500 km. Those orbital characteristics assured that the satellites would cross the equator at the same local sun time every day and also that all parts of the earth (except those in polar night) could be photographed once every 24 h.

Photographs (Fig. 2) from ESSA 3 and ESSA 5 in the ESSA series of satellites were used in this study. The photographic products used were in the form of composite rectified mosaics on mercator projection from several passes of the satellites. The products were available once a day. Because the satellites crossed the equator at the same local sun time every day and because the cyclone was slow moving, 5–15 knots, the time interval between one analyzed photograph and the other was approximately 24 h.

From the photographic products, an area approximately 30° longitude by 30° latitude containing the tropical cyclone cloud pattern was enlarged to fit a mercator projection map of known scale. The tropical cyclone cloud pattern was positioned as much as possible at the centre of the map. It was necessary sometimes to join two frames of original photographic product to achieve a good coverage of the cyclone under study. On occasions, grids on the original products were in error of about a quarter to a half of a degree. Such errors were corrected by reference to the original single frame pictures from which the mosaics were made. Transparent mercator grids with longitude and latitude lines drawn at intervals of one degree were imposed on the photographs so that the eye of the cyclone was at a grid point. In cases where



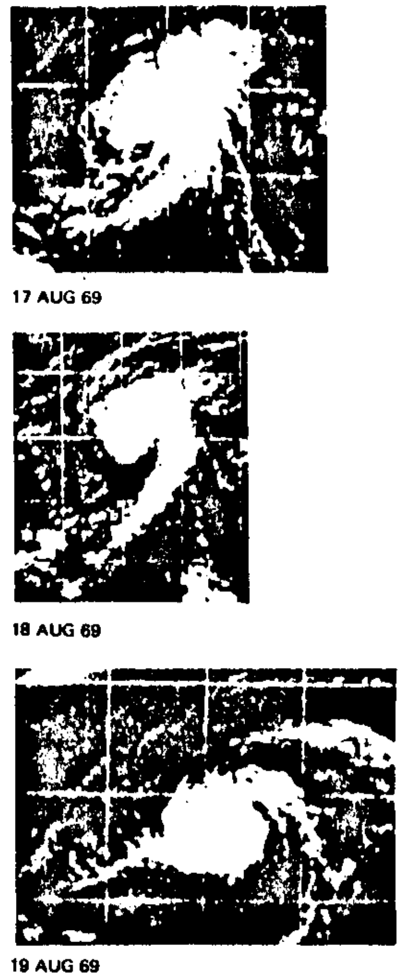


Fig. 2. Daily photographs of hurricane Debbie from Essa satellites.

an eye was not visible, the grids were adjusted so that the estimated or reported centre of the cyclone coincided with a grid point.

In carrying out computation on mercator maps, the grids made up of longitude and latitude lines were used essentially as square grids with equal distances between the grid points. As the distances between any two parallels of latitude increase at higher latitudes, the mercator grids could hardly be regarded as square grids. The greatest virtue of the mercator map however was that it had some advantageous properties near the equator. Within reasonable limits, the map was conformal and isomeric for areas in low latitude. The area of a unit square of the projection at latitude 30° is only 15% larger than the area of a unit square on the equator. For a small square close to the equator, the differential stretching of the north-south side was therefore small.

The centres of hurricane Debbie were well south of latitude 30 during the period under study. The magnitude of the errors that could be introduced into the computations because of the map projection were not large enough to affect the result of the investigation. A total of seven ESSA photographs of hurricane Debbie were analyzed for this study.

5. Analysis of ATS photographs of hurricane Debbie at one-hour intervals

Since photographs from low-orbit satellites, for example ESSA satellites, were available only once every day it was not possible to study short time changes in the cloud structure of the hurricane from them. For that part of the study, several ATS photographs of hurricane Debbie were analyzed at intervals of approximately 1 h on August 16, 1969. The ATS photographs used are shown in Fig. 8. The photographs were gridded and the cloud cover amount estimated at the grid points were transferred to a mercator map and analyzed as explained earlier.

6. Results from daily analysis of satellite-observed cloud cover of hurricane Debbie

(a) *Distribution and development of clouds*

Fig. 3 shows the distribution of cloud cover estimates in hurricane Debbie, August 1969. Fig. 4a demonstrates the information extracted from Fig. 3. It shows graphs of the variation of r_N with time for N equal to three-, five- and eight-tenths satellite-observed cloud cover for the duration of the cyclone considered. In this figure, the intensity and areal coverage of satellite-observed cloud cover over Debbie are related to its reported stage of development as given by the U.S. Weather Bureau. The quantity r_N is the radial distance from the centre of the cyclone where a specified satellite-observed cloud cover estimate N (in tenths) is most frequent. The changes in the sizes of the circles defined by r_N indicate the changes in circular area inside which values of satellite-observed cloud cover N or more are most frequent. The changes in the spacing between the curves for different values of N indicate the changes in the gradient of cloud intensity with respect to the radial distances from the cyclone centre. From Fig. 4a it was observed that r_N decreases for the three values of N chosen during the tropical disturbance and tropical depression stages of the cyclone. When the cyclone attained

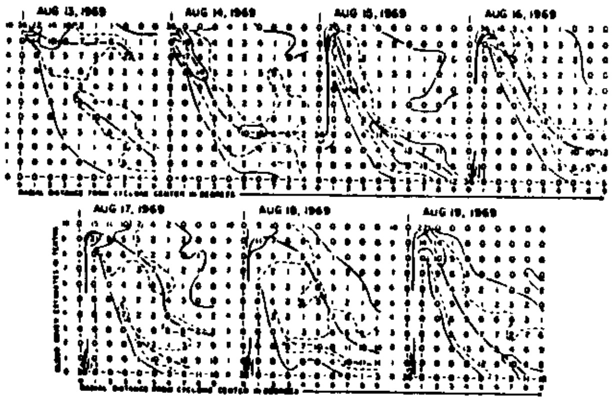


Fig. 3. Distribution of cloud cover estimates in hurricane Debbie, August 1969.

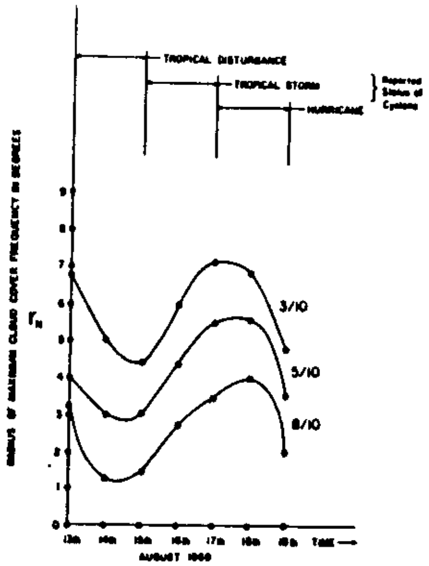


Fig. 4a. Variation of r_N with time for N equals three-, five- and eight-tenths satellite-observed cloud cover for hurricane Debbie. The information here is from Fig. 3.

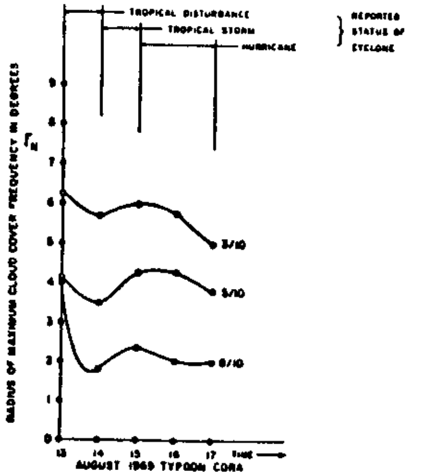


Fig. 4b. Variation of r_N with time for N equals three-, five- and eight-tenths satellite-observed cloud cover for typhoon Cora, August 1969.

the stage where it was regarded as a tropical storm, the r_N's increased and then decreased soon after the cyclone became a hurricane or a typhoon. The general decrease in r_N during the development stages indicates that the production of cloud is being concentrated into a smaller area as moist air converges on a large scale towards the centre of the growing cyclone. There is an aggregation of cumulus-type clouds into the small area at this stage of development. The increase in r_N at the tropical storm stage of the development is due to the production of cirrus clouds by cumulus towers. The internal cloud structures are hidden by cirrus clouds and cloud estimates are determined essentially by the cirrus shield. At this stage, the cyclone has become a warm core system. The expansion of the cirrus canopy continues until the winds in the cyclone system attain hurricane strength. The decrease in the cirrus canopy as the cyclone becomes mature is manifested in the decrease of r_N in Fig. 4a. This decrease is evidence that at mature stages tropical cyclones are more compact and have also modified their environment. The clear zone which usually surrounds the cyclone at this stage is evidence that downward motion is occurring at the periphery of the cyclone. The downward motion is the outer column of the thermally direct circulation which is an important feature of the tropical cyclone.

The appearance of tropical cyclones in satellite photographs is no doubt also influenced by the local patterns of winds within large scale circulation features (sub-tropical cyclones, high level mid-oceanic troughs, etc.) of the regions in which the cyclone is developing (see Sadler, 1964). For this reason, the cycle of development of cloud patterns may be different from one region of tropical cyclones to the other. One result of similar analysis of the cloud distribution in a typhoon in the Pacific carried out by the author is presented in Fig. 4b. In this figure r_N is plotted against time as in Fig. 4a. It is noted that the variation of r_N with time is similar to that of Debbie, however we do not have the same values of r_N's for the different stages of development of the cyclone.

From the foregoing discussion it may seem impossible to establish a relationship between the size of cloud cover of a tropical cyclone system and the intensity of the cyclone. While r_N may vary in the same manner for all hurricanes, the values of r_N are not necessarily the same for the same stage of

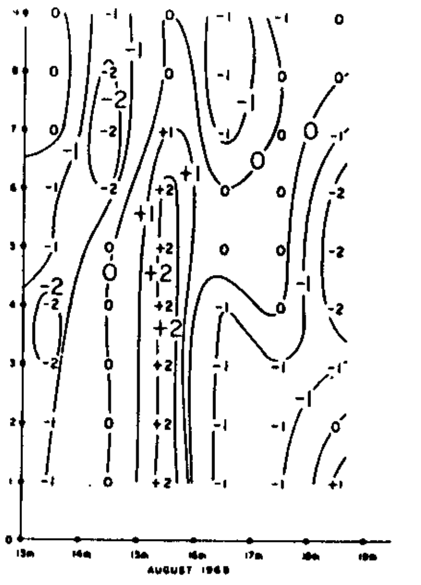


Fig. 5. Daily changes in tenths in the mean cloud cover at the various radial distances from the centre of the hurricane for the period under investigation.

development. This fact emphasizes the difficulty encountered in the process of developing a useful relationship between the cloud patterns of tropical cyclones as shown in satellite photographs and their maximum wind speeds. Some researchers (e.g. Fritz et al., 1966), as mentioned in an earlier section, established some relationship between cloud patterns and the intensity of cyclones which permitted the estimation of the intensity of the tropical cyclone from the satellite-observed cloud patterns alone. The relationship often underestimated the intensity of the cyclone when used with independent data, partly because the photographs used in establishing the relationship for the various levels of cyclone intensity were from different cyclones and partly because of the considerable subjectivity in the determination of the cloud pattern sizes and category of the cyclones. That rendered the relationship between cloud patterns and intensity of cyclones developed by Fritz and others only of limited use. Direct proportionality between the intensity of the cyclone and the size of the cirrus shield seem only likely during the period of rapid intensification. Before and after that period such direct proportionality does not seem to exist.

Fig. 5 shows the daily changes in the mean cloud cover at the various radial distances for the hurricane for the period under consideration. This diagram shows a general decrease of mean cloud estimates at the various radial distances during the tropical disturbance and tropical storm stages of the hurricane. From the diagram there is an explosive development of clouds between the 15th and 16th of August just at the time the cyclone is reported to be developing hurricane strength winds. Thereafter, there is a general decrease in cloud cover estimates. Noticeable also is the decrease in cloud estimates at the periphery of the storm during the period of investigation of the storm. This observation is evidence of downward motion at that region of the cyclone. The information contained in the diagram could not have been obtained by mere inspection of the photographs.

(b) *Results from harmonic analysis of the sequence of cloud photographs*

The curves on the polar diagram Fig. 6 showing the phases for the first and second harmonics reflected the different orientation assumed by Debbie during its evolution. The curves for the first harmonic indicated the general direction of the cloud development. Because of the predominance of that component, it can be inferred from the polar diagram that the preferred direction of major cloud concentration and development is the SW–NE direction (especially near the centre) during the early stages. As the cyclone matured, the direction of major cloud development shifts N–NE. A general inspection of the sequence of the curves for the first harmonic in the polar diagram indicates a cyclonic rotation of the portion of the curves near the centre of the cyclone, while the portion of the curves further away from the centre tend to recede. A more definite statement about the shift in the phase curves could be made if it were possible to account for the change in the direction of motion of the cyclone itself in the orientation of the phase curves. In the analysis of the hourly photographs of the hurricane reported below it was possible to make a definite statement about the orientation since the direction of motion of the cyclone was fairly constant during the period of that investigation. The curves for the second harmonic behaved in the same general manner as those of the

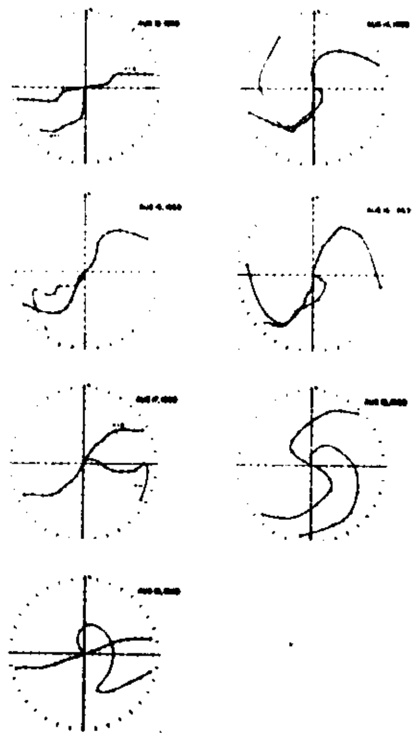


Fig. 6. Phase curves for the first and second harmonic components.

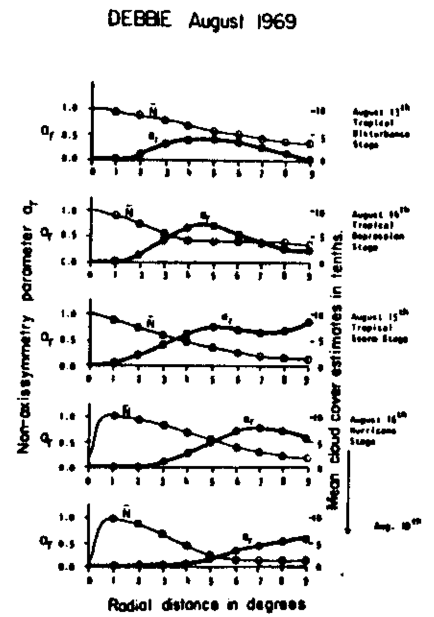


Fig. 7. Graphs of a_r as a function radial distance and time. Graphs of $\bar{N}$ are also indicated on the graphs.

first harmonic. One important feature of the curves for the second harmonic is that they closely indicate the general orientation of the cloud patterns at all stages more closely than those of the first harmonic.

(c) *Measure of the asymmetric nature of the cloud patterns*

A quantitative measure of the non-axis symmetry of the cloud distribution is given by the parameter a_r defined earlier. From Fig. 7 it is observed that a_r has a maximum close to the centre of the cyclone at the early stages of the cyclone but the location of this maximum moves outwards as the distribution of the cloud becomes more symmetrical with respect to the centre of the cyclone. One can infer that at the early stages of the tropical cyclone more clouds and hence more rigorous vertical motion is located in a particular azimuthal direction but then spreads completely around the centre of the cyclone as the cyclone develops. The mechanism for the redistribution of vertical motion is not very clear.

7. Hourly cloud analysis of hurricane Debbie

In order to investigate short-term changes (matter of hours) in the cloud structure of Debbie using the photometric method, seven ATS photographs of the cyclone taken at roughly hourly intervals on August 16, 1969 were analyzed. Fig. 8 shows the photographs. Fig. 9 shows the graphs of three-tenths, five-tenths and eight-tenths cloud cover as function of radial distances and time computed from a frequency distribution of cloud cover amounts. From Fig. 9 it is observed that there is little change in the cloud structure over a period of several hours. This view is also supported by Fig. 10 which shows the changes in the mean

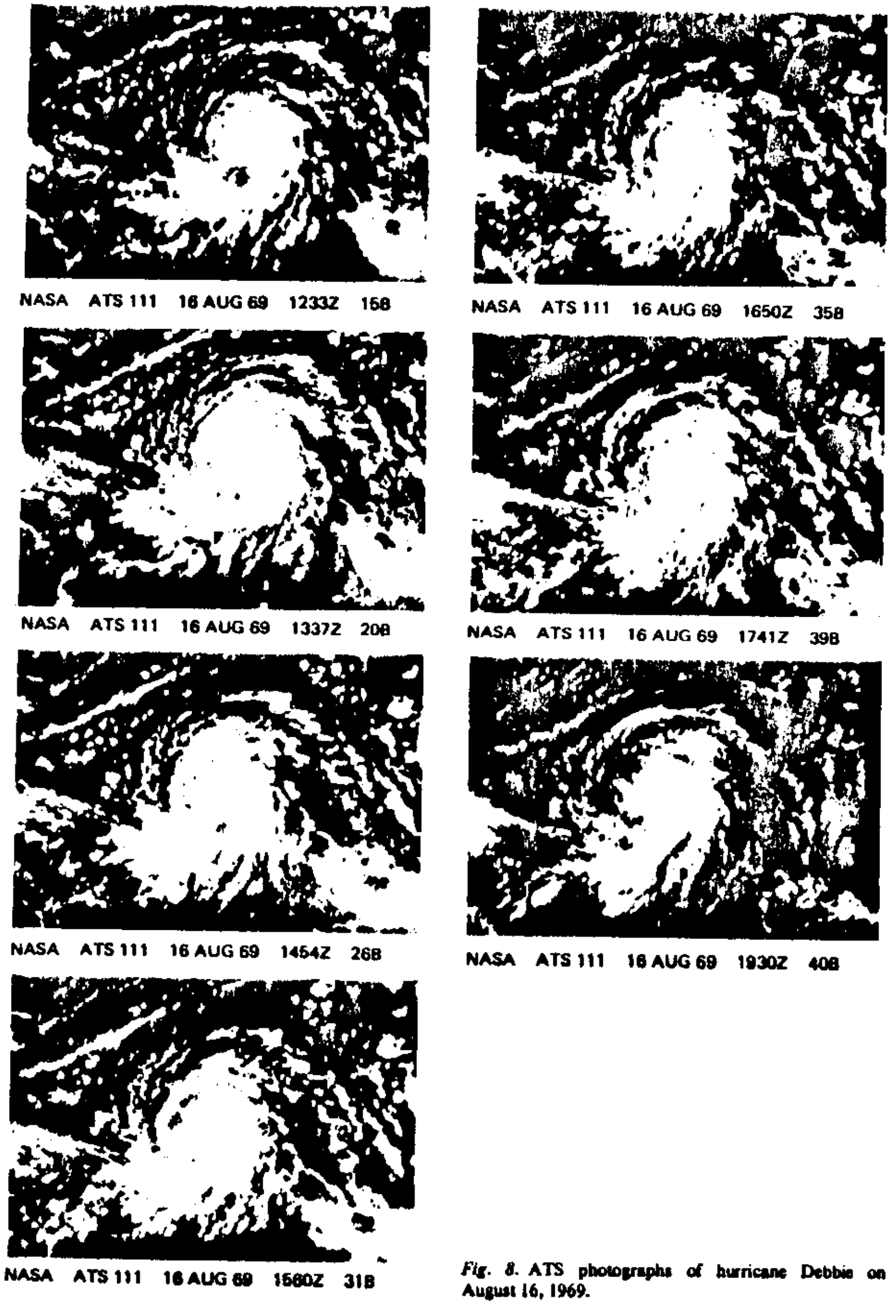


Fig. 8. ATS photographs of hurricane Debbie on August 16, 1969.

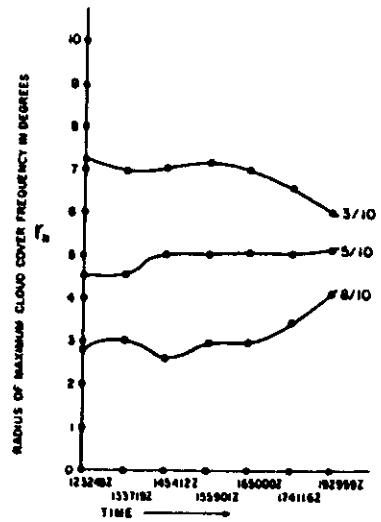


Fig. 9. Graphs of three-, five- and eight-tenths cloud cover as function of radial distances and time computed from a frequency distribution of cloud cover amounts for the hourly data.

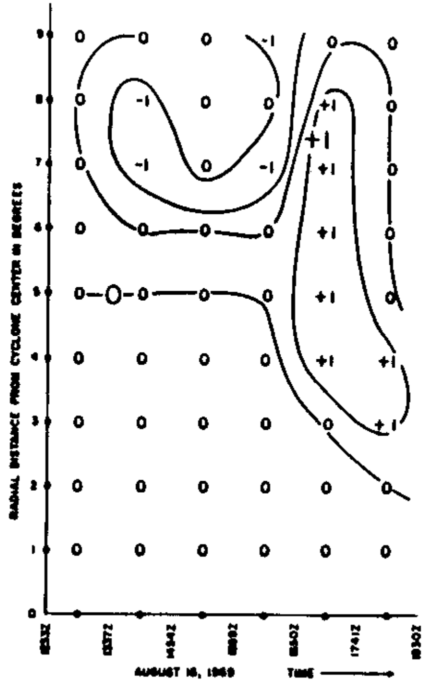
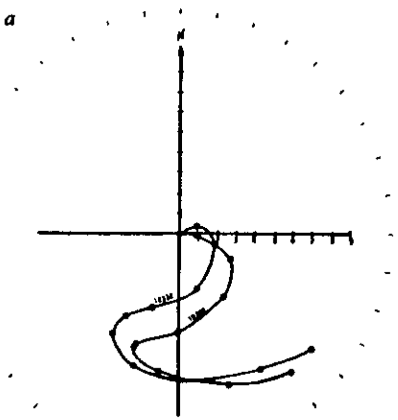


Fig. 10. Hourly changes in cloud cover estimates at various radial distances and time for hurricane Debbie on August 16, 1969.

values of cloud cover estimates at the various radial distances during the period of 7 hours.

Figs. 11a, b show the shift in the phase curves for the first and second harmonic during the 7-h period. From reports the cyclone was moving in roughly the same direction throughout the period. Therefore the rotation of the phase curves which are hereby associated with cloud bands could not be due to a change in the direction of motion of the cyclone but an indication of the cyclonic rotation of the field of convergence. From the figure, one notices that the shift is cyclonic for both harmonic components within 7° of the cyclone centre. Outside that region the shift was anticyclonic. From the two diagrams the rotation rates of the two curves are compared with the rotation rates of air particles in a fully developed cyclone system with maximum wind equal to 40 metres per second and a wind profile of $V_\theta r^{0.5}$ = constant outside the radius of maximum wind, here taken as 50 km. The result is shown in Fig. 12. In this diagram the rotation rates of phase curves and air particles are indicated as functions of radial distances. Curve A shows the rotation rate of air parcels. Curve B shows the rotation rates of phase curves for the first harmonic components. Curve C shows the rotation rates for phase curves for the second harmonic components. These curves suggest that the rate of rotation of cloud bands is usually less than the rate of cyclonic rotation of air parcels about the centre of the cyclone. From Fig. 12 the rate of rotation of the cloud bands is about 50–75% of the rate of rotation of air parcels.

However, comparing the hourly phase curves for hurricane Debbie on August 16, 1969 with the daily curves for the same cyclone it is observed that the daily shift of the phase curves cannot be extracted from the rate of rotation of the phase curves computed from the hourly curves. In fact, the phase curves for the second harmonic compo-



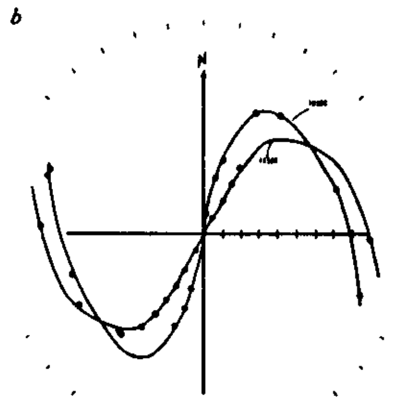


Fig. 11a. Shift in the phase curve for first harmonic between 1233Z and 1930Z for cloud patterns of Debbie on August 16, 1969.

Fig. 11b. Shift in the phase curves for the 2nd harmonic between 1233Z and 1930Z for cloud patterns of Debbie on August 16, 1969.

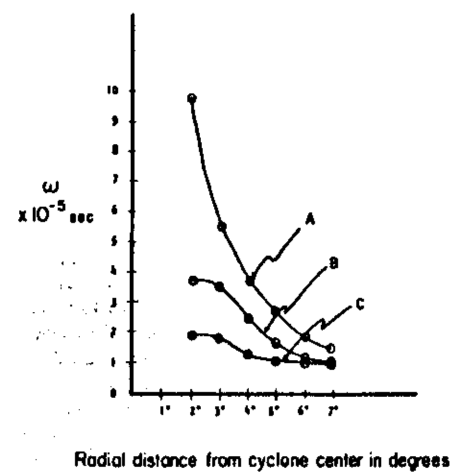


Fig. 12. Rotation rates of phase curves and air parcels as function of radial distances. Curve A shows rotation rates of air parcels. Curves B and C show the rotation rates of phase curves for the first and the second harmonic respectively.

nent for August 16 and 17, 1969 show a recession. This suggests that there may be local oscillations of the cloud bands during the development of cyclones and that rotation rates computed from Fig. 12 may have overestimated the rotation rate of the cloud bands. It also indicates the complex nature of the tropical cyclone system.

8. Prospects of the analysis of satellite radiation maps of tropical cyclone

Quantitative measurements of radiation emitted from clouds offer another set of data that can be analyzed in a manner described by Balogun (1977). The result of the analysis of digital maps of high resolution infrared radiation data of hurricane Inez (Hubert et al., 1969) pointed to the possibility that earlier methods of analysis of the visible imagery of cyclones can be extended to the analysis of infrared cyclone patterns. The analysis of radiation data

however, demands more care than the analysis and interpetation of satellite photographs. The reasons for this cautionary note are many and varied. First, there are uncertainties of the absolute values of such measurements due to calibration problems. Secondly, considerable information may be lost during data conversion procedures and interpolation of data may vitiate the final results. Thirdly, there are usually imponderables associated with the translation of radiances into the appropriate atmospheric temperatures. These do not exhaust the difficulties involved in the use of radiation data. These and other problems make radiation data less attractive to use than the photographic data. The best uses of radiation data so far are in climatological studies covering wide areas.

Recent advances in the study of radiative properties of cloud and in the development of more sophisticated radiometers that can be carried by satellites may alleviate some of the difficulties associated with the use of radiation data. Presently it is possible to infer cloud heights and amount from observations from selective Chopper Radiometer carried by Nimbus 5 satellite. The procedure for doing this was explained by Wrigley & McGleeze (1976). Also it is now possible to obtain microwave radiation from precipitating clouds by spectral radiometers that can be mounted on satellites. These radiometers can be used to detect precipitation over land as well as over the sea as explained by Savage & Weinman (1976). If the response of infrared radiation sensors in orbit can be kept at the same level for long periods and data from limited areas reliable, then infrared displays of tropical cyclones can be subjected to the same analysis as used in this paper. It may then be possible to separately analyze cloud cover at different heights—which is not possible with the method used in this paper—to study the distribution and movement of major rain areas within the cyclone system and to obtain integrated totals of liquid water through the depth of clouds associated with the cyclone system and thereby have a better idea of energy transformations within the cyclone system.

During the Global Atmospheric Research Project Atlantic Tropical Experiment, June–September 1974, some infrared displays of tropical cyclones developing over the eastern Atlantic and moving westward were obtained. These data are now available for analysis by the author and other research workers. These data and others collected during the experiment will enable a better classification of tropical cyclones, which will be based on more complete data than available hitherto.

9. Conclusions

Through detailed analysis of a series of satellite photographs depicting the various stages of hurricane Debbie, the following points are noted.

(a) The gradual changes in the cloud cover estimates as the cyclone develops are indicative of orderly, even, though complicated, physical processes taking place in the cyclone system. Only small fluctuations in the cloud cover estimates—one to two tenths—are noted from day to day.

(b) The spatial distribution of the cloud cover estimates vary with the development of the cyclone. The curves showing the changes in the spatial distribution of cloud patterns in Figs. 4a, b illustrate the three major periods into which the life history of the tropical cyclone can be divided. These three periods are: The early development period during which the aggregation of cumulus cloud into smaller area gives an indication of the incipient cyclone, the period of rapid intensification characterized by the development of the cirrus shield over the cyclone system—the cirrus shield increases with time during this period—and the third period is the period between the time the cyclone attains hurricane or typhoon strength winds and the time the cyclone attains its maximum intensity. During the third period, the rate of expansion of the cirrus shield first increases and then decreases as the cyclone modifies its environment; thereafter the cyclone degenerates.

To study the changes in the orientation of cloud patterns of the cyclone as the cyclone develops, phase curves are drawn for the first and second harmonics. These phase curves are curves joining the positions along each circle for all the nine circles drawn on each cloud pattern. The phase curves are identified with cloud bands and hence with the field of low level convergence and with the cirrus outflows from the towering cumulonimbus clouds that result from the low-level convergence. Compared to the rotation of air particles around the centre of cyclone, the rotation of the phase curves is very slow. Although computations in this study show that the rates of rotation of the first and second harmonics are rather high, the fundamental fact that they are slower than those of air parcels is indicated.

In conclusion, it is noted that no diagnostic types of tropical cyclones will run true to form in all respects. Each cyclone has its own unique characteristics. No two cyclone systems are entirely alike either in structure or behaviour. When several cyclones are analyzed the same way as Debbie, the results should guide the thinking in the objective and refined classification of the different stages of development of the tropical cyclones.

10. Acknowledgement

These analyses have been possible through the use of facilities at the Satellite and Meso Meteorological Research Project of the Department of the Geophysical Sciences, University of Chicago, U.S.A. I am very grateful to the Director and the members of the project for making this work possible.

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ДИАГНОСТИЧЕСКОЕ ИЗУЧЕНИЕ РАСПРЕДЕЛЕНИЯ И РАЗВИТИЯ ОБЛАЧНОСТИ ПО СПУТНИОВЫМ ДАННЫМ В УРАГАНЕ ДЕББИ 13–19 АВГУСТА 1969г

Представлены результаты диагностического изучения распреде ления и развития облаков в урагане Деббм в период с 13 по 19 августа 1969 г. Исследование основывалось на спутниковых данных и проводилось с помощью фотометрического метода, описанного ранее Балогуном (1976). Систематическая оценка облачности тропического циклона над океанами достаточно объективным методом выявляет следующие особенности циклона:

(1) Постепенные изменения характера распределения облачности тропического циклона. Изменения происходят определенным образом.

(2) Неосесимметричный характер распределения облачности. Степень несимметрии на ранних стадиях развития циклона оценена количественно. Полученный параметр несимметрии используется затем для демонстрации процесса симметризации на поздних стадиях циклона.

(3) Скорость вращения облачных полос относительно оси циклона меньше скорости вращения воздушных частиц относительно оси вращения. Скорость вращения полос по оценке составляет от 50 до 75% скорости вращения частицы воздуха. Эта оценка относится к периоду около 7 часов времени жизни циклона. Более низкая скорость движения полос позволяет предположить, что поле конвергенции на низком уровне движется со скоростью относительно оси циклона, отличной от скорости воздушных частиц.