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AIR WEATHER SERVICE
TECHNICAL REPORT 105-37

REPORT ON THE OFF-SEASON OPERATIONS OF THE AIR FORCE HURRICANE OFFICE 1947-1948

COELUM AD PROFICUM ELIGE

JULY 1948

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July 1948

Air Weather Service Technical Report 105-37, "Report on Off-Season Operations of the Air Force Hurricane Office, 1947-1948," is published for the information and guidance of all concerned.

BY ORDER OF COLONEL SMITH:

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INTRODUCTION

The following Weather Officers of the Air Weather Service participated in this project: Captain Newton M. Burgner, Captain Verl D. Dotson, Captain Hugh W. Ellsaesser, Captain Herbert W. Graham, 1st Lt. Stanley J. Kimball, 1st Lt. Emil E. Renberg, CWO Richard H. Miller. During the period between the end of the 1947 hurricane season and the beginning of the 1948 season, a group of weather officers working in the Air Force Hurricane Office, Miami Air Force Base, Miami, Florida, was engaged in the study of certain features of the hurricane-warning service as it concerns the Air Force and Army requirements. This program was initiated by the Air Weather Service, when it placed the operation of the Air Force Hurricane Office on a year-round basis.

The Hurricane Office was given three specific operational problems for study during the non-hurricane season:

1. Improved utilization of aerial reconnaissance in the hurricane-warning service;

2. Analysis of the past hurricane-forecasting performance with a view to selection of the best techniques; and

3. Supplemental analysis of tropical storms of the preceding season in order to determine what problems require basic research by appropriate agencies.

Rather than to attempt to cover the entire field of hurricane forecasting, the group was advised to concentrate on forecasting direction of motion of tropical cyclones, forecasting changes in tropical storm intensity, and determination of a general synoptic model of a tropical cyclone. This report presents the principal results of the study conducted by the Air Force Hurricane Office during the period of the first off-season operation, November 1947 - May 1948.

Detailed supplemental analyses of the storms of the 1947 season will not be included here but are on file for reference use in the Hurricane Office along with the auxiliary charts, maps, cross sections, and the reports of Air Force and Navy hurricane-reconnaissance flights of the 1947 season.

UTILIZATION OF AERIAL RECONNAISSANCE

One of the primary purposes of the first off-season program was the study of the utilization of reconnaissance in hurricane forecasting. Two main goals were kept in mind for this project -- to study the accuracy of reported fixes of storm location and navigation techniques and to investigate the possibilities of expanded application of reconnaissance to hurricane research. In view of the close relation between the efforts of the personnel of the Hurricane Office and the Weather Reconnaissance Squadron, a plan to indoctrinate and familiarize the forecasters of the Hurricane Office with the techniques and procedures of reconnaissance was established by Headquarters, 8th Weather Group. A program of training, including ground and in-flight instruction, was established at the 373d Reconnaissance Squadron Headquarters at Bermuda. Ground training included study of the purpose of weather reconnaissance, the duties of the weather observer, and related subjects of navigation. In-flight training comprised an actual mission with the forecaster flying as a student.

Besides the valuable results received from the indoctrination program certain other information has been assembled and will be presented here. Particular attention will be given to the matter of navigation techniques and the accuracy of fixes of storm location.

It should be pointed out that the major portion of Atlantic hurricane reconnaissance by the Air Forces during the 1947 season was performed by B-17 aircraft with some use of B-29's. The B-17 aircraft were used for low-level reconnaissance and for penetration to the storm center, while the B-29's were usually flown at high levels. Plans for the 1948 season include use of only B-29's in hurricane reconnaissance.

Low-altitude flying in a hurricane is characterized by high winds, low ceilings, poor visibility, heavy rains, and turbulence varying from light to serious. It is generally agreed that the south side of a hurricane is the least active while the northeast sector seems to be the worst. Most penetrations are therefore made from the south.

After a definite track to the storm center has been taken and winds of hurricane force are encountered, various precautions are taken. The superchargers are turned up, propeller pitch is increased slightly, and the fuel booster pumps are placed in the ON position. When encountering heavy rain the power is usually increased in order to keep oil and cylinder-head temperatures at a level sufficient to prevent engine failure. It is quite often necessary to lower the landing gear to keep the airspeed from building up above reasonable limits.

Near the eye of the storm winds of maximum velocity increase drift as much as 47°. Some B-17 pilots have noticed difficulty in making turns during these conditions. At such times a constant check must be kept with the weather observer for the correct altitude readings. With these the pressure altimeter is adjusted, usually being set 100 feet lower than the actual altitude to compensate for the rapid drop in pressure.

Methods of crew cooperation when the storm is encountered may vary, but it is noteworthy that no penetration is attempted without a set policy of crew coordination being planned beforehand.

Low-level penetration of a hurricane cannot be judged by experience in any particular storm since the degree of turbulence varies from storm to storm and for various penetrations of the same storm. In one isolated case the downdraft near the eye was so strong that the aircraft dropped 450 feet, to 100 feet altitude, almost instantly. Full takeoff power was quickly applied but for some seconds the B-17 maintained only 140 mph airspeed at 100 feet. In another storm with winds of similar intensity only moderate turbulence was encountered in small areas, and at no time did the aircraft deviate from its intended altitude of 500 feet by more than 50 feet.

The two main techniques of navigation which were used for low-level penetration by B-17 planes during the 1947 season were the 270° method and the single-track method. Explanation of these techniques will be presented as a means of evaluating the observations made by these methods.

1. The 270° Low-Level Method

Contact flight conditions must exist for absolute accuracy of navigation, but instrument conditions for very short periods of time (2 or 3 minutes) do not hamper accuracy to any great degree. The storm is entered from a southerly direction, and throughout the penetration the wind at all times is kept at an angle of 270° to the nose of the aircraft.

The navigator takes double-drift readings regularly as an accurate check on the groundspeed and position of the aircraft. Drift, compass heading, indicated airspeed, and time are read every 2 to 4 minutes and recorded. After each correction a new drift reading is taken simultaneously with observations of indicated airspeed and compass heading. Time corrections are made and noted in the navigation log. As the center of the storm is approached the winds shift counter-clockwise more rapidly and constant course corrections are necessary.

Comparatively calm conditions and the lowest barometric pressure indicate penetration and location of the center of the eye. Notation of the time of arrival at this point is made. The times are also noted as the eye is penetrated and as it is left. Thus the time taken to fly the diameter of the eye is provided and the diameter of the eye can be calculated.

If the storm is in an area of good Loran coverage, an exact fix of the location of the center can be made by that method. If no Loran facilities are available the navigator plots the position of the center of the storm immediately upon leaving the vicinity, by using the data from his log.

Immediately after leaving the eye of the storm a double drift is taken to obtain maximum wind velocities. The navigator then plots the position of the aircraft in the eye of the hurricane as quickly as time and turbulent conditions permit accurate chart work. This information is furnished to the weather observer for inclusion in his report.

2. Single-Track Method (Low Level)

Since the exact position of the eye is unknown before penetration and because a track flown continuously perpendicular to the wind becomes curved, the quadrant of entry will depend on the distance flown to reach the eye. Furthermore, since it has been found that certain quadrants of the tropical cyclones are more violent than others it is sometimes preferable to enter through the less active sectors. In order to accomplish this the "single-track method" has been developed.

Assuming that the direction of approach is from the southwest, the course is flown from the base at "A" to point "B" (See Figure 1), 100 miles to the west of the estimated position of the eye. If the center proves to be closer than predicted, the course can be changed to select "B" further west so that the aircraft will be kept out of the more severe weather. The choice of "B" usually depends on reaching a position where the winds are directly from the north and the course is then changed to the southeast or perpendicular to the path of desired approach to the center. By constant checks on the winds and pressures a point "C" will be reached where the winds have changed direction from the left rear of the aircraft to direct tailwinds; the pressure will remain constant for a moment and then begin to increase. This point is noted and the track is continued to "D" where the winds have shifted to the right rear and the pressure shows a definite increase. The bearing of the center will have been established as being perpendicular to track "B-D" at point "C." The aircraft is then turned and headed back toward "C" and, since allowance for storm movement must be made, the plane is flown to "E" where a turn is made on the perpendicular track established by the pressure-pattern bearing. Drift is read as long as it is possible to keep on the single track. During the last few minutes before reaching the eye the plane is kept with the wind coming from ten o'clock in order to insure that the eye will not be missed.

Variations of path and approach are possible with this method, and the pressure pattern is calculated outside the area of most severe weather.

Navigation accuracy at low levels is no problem during the daylight hours. Drift is usually easy to read and the wind direction and velocity reports are accurate because of the double-drift readings. Loran gives the most accurate fixes possible and its reception in the eye is excellent

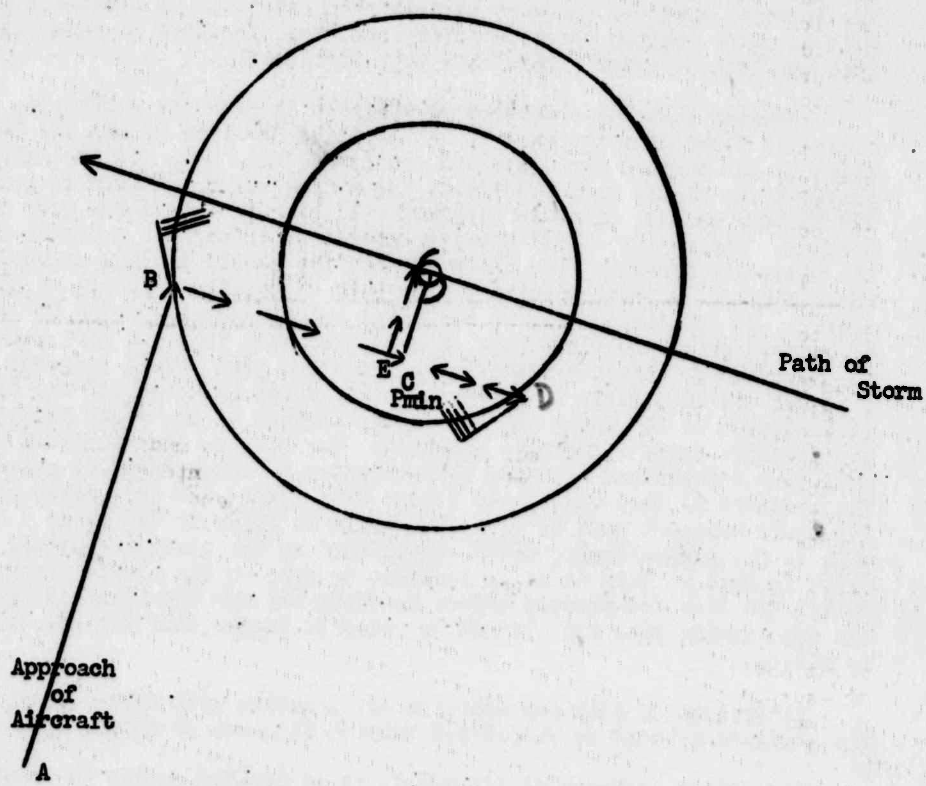

FIGURE I
SINGLE TRACK METHOD OF TROPICAL CYCLONE PENETRATION
BY AERIAL WEATHER RECONNAISSANCE

in the areas covered by Loran stations. (Loran coverage does not extend throughout the Caribbean and Gulf of Mexico.)

When radar fixes are taken the fix is considered as accurate as the instrument and the aircraft position from which the observation is made. Radar observation of the center from high-level B-29 flights will be studied during the 1948 season. Observations from the 1947 season indicate no perceptible tilt in storms between the surface and 10,000 feet.

3. Proposed Circumnavigation Method (Low Level)

Plans of the 373rd Reconnaissance Squadron (Weather) for 1948 reconnaissance assume the use of B-29 planes. While successful low-level penetration was accomplished during the 1947 season, precautions are being considered for low-altitude flight of these planes in hurricanes. Such measures will include recommended techniques of observation to provide greater detail and variety of data.

In the proposed method of hurricane investigation by B-29 flights at low levels, the storm is approached along a line parallel to the storm track in the southerly section of the storm but at a greater distance from the center than in the 1947 penetration method. (See Figure 2.)

If the course is flown from the base at "A" the direction of approach in this method would be from the southeast, to establish a base line parallel to the storm track, assuming that the storm is moving towards the west. Points "B" and "D" on the base line would again be established with the wind having veered approximately 90° between them and with equal pressure readings observed at their locations. Point "C" would lie at the pressure minimum between these points, and theoretically along a perpendicular to the center. At "D" a 90° turn to the right would be made and a true course maintained until hurricane winds (75 mph) were encountered, establishing point "E". Selection of this point would also depend on the ceiling encountered, since contact flight must be maintained and flight below 1,000 feet is considered hazardous. In cases of immature storms some other arbitrary value of wind velocity would serve as an index.

Having reached the region of hurricane winds, another 90° turn to the right would be made at "E" and continuous observations, particularly of pressure, would be taken. Point "F" would be established as the point of minimum pressure along this new course and the track would be followed until a point "G" was reached where the pressure would be the same as at point "E" but the wind direction approximately reversed.

At "G" a 90° turn would be made to the left and subsequent establishment of points "H," "I," "J," "K," and "L" would follow as the storm was

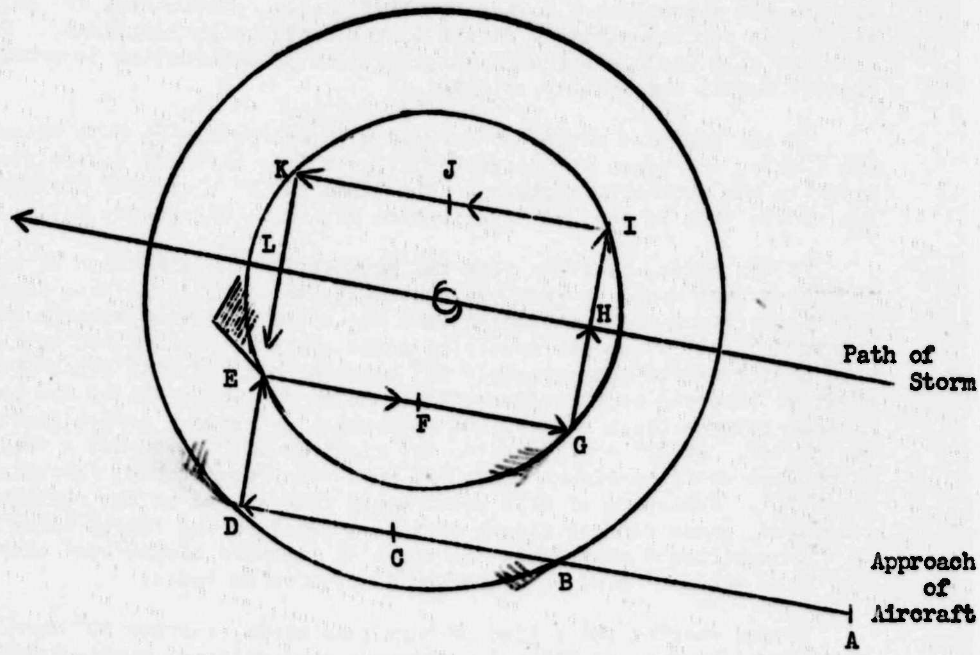

FIGURE 2
PROPOSED TROPICAL CYCLONE CIRCUMNAVIGATION METHOD (LOW LEVEL)
BY AERIAL WEATHER RECONNAISSANCE

circumnavigated with "E," "G," "I" and "K" being located on the same isobar and "F," "H," "J," and "L" being the minimum-pressure points on the successive right-angle tracks around the storm center.

Observations taken at the strategic points would be transmitted as soon as possible so that the storm center could be determined by the forecasters at the Hurricane Center.

This method would facilitate better dead-reckoning navigation, supply valuable information concerning all sectors of the storm, and eliminate the hazardous operation of entering the extremely violent area of the hurricane.

4. Examples of the Problem of Reconnaissance Accuracy in 1947 Season

The problem of accuracy in reconnaissance reports is not confined to the matter of center location. During the 1947 season several reports were noted to be questionable with regard to multiple centers, false centers, and closed cyclonic circulation.

Wexler points out that an observer viewing the local weather from a microscopic point of view, especially during bad weather, has his vision greatly reduced. Even when good visibility exists, this point of view reveals "only a few threads of the large fabric of the atmosphere and sometimes this microscopic view gives misleading information concerning the design and speed of the approaching weather."

Storms Dog and Easy are discussed in another part of this paper but it should be noted here that the report by Weather Reconnaissance which was used as the basis for forecasting movement of storm Dog inland appears on re-analysis to have been a report of a strong trough line rather than a storm center, and that the apparently subsequent storm Easy was in reality the continuation of the original storm Dog.

Again, in the discussion of storm King, it will be seen that the previously held theory, that a separate storm formed with radical westward movement into Georgia, has been discarded in favor of the idea that the original storm underwent the process of recurvature to the west. In this connection, the reconnaissance radar report of the location of two centers has been disregarded because the weight of evidence indicates that the allegedly separate storm area reported to the north was actually a region of squally weather, while the true center was located to the south. It is considered that this original storm center continued on its course into Georgia.

In the reconnaissance on storm Love, the early report of cyclonic circulation appears questionable because of the subsequent failure to find such circulation until two days later when it was located in an area definitely removed from any anticipated movement of the original closed circulation.

It is not intended to discredit the results of reconnaissance by these examples, but rather to point out particular instances of problems that have arisen and to stress the importance of the utmost accuracy in the reporting of such observations from the "microscopic" point of view of the aerial weather reconnaissance observer. The use of the circumnavigation method of storm location may well prove or disprove the type of analysis outlined above.

5. Amplification of Tropical-Cyclone Analysis Through Aerial Reconnaissance

Special attention was given by the off-season program to the possibilities of expanded application of reconnaissance to hurricane research. Attention was first devoted to the reports themselves. Observations taken aboard reconnaissance planes usually are encoded and transmitted by radio. Rather than burden the observer and radio operator with additional code groups to be provided and sent under difficult flight conditions, it is recommended that a log and report of supplemental data be prepared by the crew during or as soon as possible after flight. These reports should include an overall description of the storm system with special reference to the eye and how the storm may differ from previous days or from other storms. Record should be made of criteria by which the eye was identified and of the estimated accuracy of navigation and visual and radar fixes of the storm location. Comments on the character and distribution of clouds, winds, turbulence, vertical currents, precipitation, and sea swells would be of value. Personal comments of the weather observer and other crew members concerning the operational behavior of the aircraft in the storm, failure of instruments, or inability to make observations also are suggested for inclusion in the flight report.

Mechanical means of recording such information were undergoing experiment during the past season. Wire recording machines were installed in planes so that weather officers could record their observations and provide a descriptive running account of storm features even when extreme turbulence made writing impossible. Recording devices which provide continuous traces of pressure, temperature, relative humidity, and airspeed were introduced as another attempt to provide augmented data. Continued trial of such devices is definitely recommended.

Prompt delivery of this information would be of value to the operation of the Hurricane Warning Service. Its collection would provide important data for future research by all interested meteorological agencies.

Absence of upper-air observing stations in areas of hurricane frequency makes it virtually impossible to verify, disprove, or develop theories of hurricane forecasting involving the use of data at upper levels. The only solution to this problem likely to give results in the near future is for reconnaissance aircraft to fly special missions and tracks at low and high levels in definite patterns for the specific purpose of accumulating such information.

When a storm is far from land a continuous check of the location and intensity of the center is not too essential and high-level missions to collect research data would be feasible without endangering populated areas. Circumnavigating a storm and locating the center provides data which are necessary but yet will probably not greatly advance our basic knowledge of tropical cyclones and their movement. More accurate and longer-range forecasts of cyclone movement will likely result only when we are able to give greater attention to the air mass in which the storm is imbedded.

Following are the types of observations considered necessary to test the hurricane-forecasting theories:

1. Tracks of constant true altitudes (by radio altimeter) from 15,000 to 40,000 feet, normal to the path of the storm, through its center and extending to 500 miles in advance and to the rear of the center with accurate temperature recordings at 5-minute intervals;

2. Aircraft soundings in the eye, at approximately 100 miles ahead, to the rear, and to either side of the eye, and to either side of the probable storm path as far as 500 miles in advance of the storm center; and

3. Tracks circling the storm center at constant radio altitudes below 3,000 feet, obtaining wind observations in each of the four cardinal directions from the storm center as nearly as possible on the same isobar.

Such tracks would supply data for investigation of the theories of warm-tongue and isotherm steering, and strongest wind or isobaric-channel-transport steering, as well as provide details for theoretical and empirical analysis of hurricanes.

Considerable attention in hurricane forecasting has been given to the theory of locating a steering level which controls the course of a storm. The assignment of B-29 aircraft to hurricane reconnaissance makes it possible to investigate upper steering-levels and to examine storm phenomena at high altitudes.

In this connection, it would be desirable to have available the results of traverses made simultaneously at different altitudes in a hurricane. It is realized that storm hazards and limitations of navigating techniques make such a project impossible at this time, but the value of data which would be provided by intensive sampling of all levels and sections of individual storms should be emphasized. It is hoped that progress may be made towards the accomplishment of this goal and that the concerted investigations recently made on thunderstorms may have their counterpart in the study of the hurricane.

Accumulation of photographs taken in storm areas and intensified effort to take such pictures are additional projects recommended for development. Documentation of the photographs with reports of parallel observations and experiences would be particularly profitable. Pictures of radar-scope observations should be given special attention for the additional purpose of improving the technique of radar reconnaissance.

Use of radar to investigate tropical storms introduces the concluding recommendation for the further use of reconnaissance. Experimental aerial radar coverage of hurricanes during the 1947 season in the North Atlantic and Gulf of Mexico gave promising information, especially during night observations. Continued development of this facility is considered essential to provide thorough tracking of storms. It will, for example, permit adequate warning of sudden recurvature toward the land when a hurricane is a short distance offshore. Furthermore, it will make possible the definitive analysis of storms and their trajectories at times when they seem to be erratic and unusual.

While it is obvious that certain of the recommendations and suggestions that have been made here are dependent upon a much greater concentration of personnel and aircraft in the hurricane reconnaissance program than is now possible, and that others must wait for basic technical improvements, these ideas are presented as a guide to the functional expansion of the aerial reconnaissance program as it concerns the Hurricane Warning Service.

1947 HURRICANE SEASON

1. Summary of 1947 Tropical Cyclones

The Air Force Hurricane Office at Miami, Florida, issued AF Bulletins on 12 Atlantic storms during the 1947 season. One of these was definitely extratropical, a second was probably extratropical, and a third was the continuation of a storm which was believed to have passed inland and dissipated. This leaves 9 storms for consideration during the post-season period, as compared to the 7+ annual average for the Atlantic area.

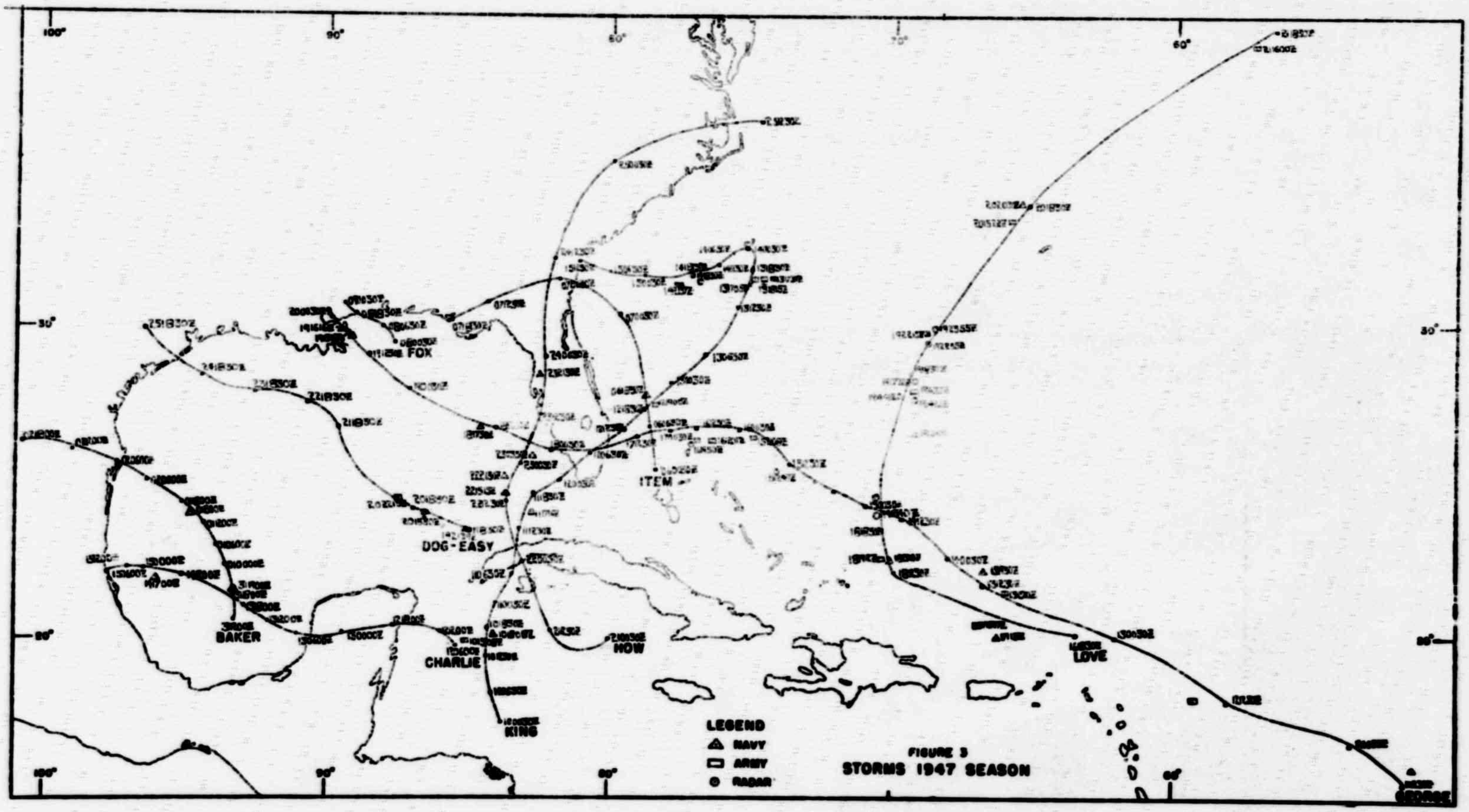

FIGURE 3
STORMS 1947 SEASON

FIGURE 3

Of these 9 storms, 5 reached hurricane intensity at some time during their life history and 2 of these passed within 40 miles of Miami. A short account of the life history of each of the 9 tropical cyclones is given below; special information on the life and intensity of each storm is contained in Table 1. The storms have been assigned phonetic alphabetical designations, but since storm Able was extratropical the summary which follows will start with the second storm of the season, storm Baker.

BAKER. Storm Baker developed from an easterly wave as it moved into the semi-permanent trough in the Gulf of Campeche. The easterly wave can be followed across the Atlantic and Caribbean for 10 days prior to its movement under an upper trough and the development of a tropical cyclone approximately 150 miles WNW of Campeche on 31 July. Once formed, Baker moved NNW, curving to the left in an arc until it passed inland about 20 miles south of Brownsville, Texas, on 2 August. Navy aerial reconnaissance flights on 31 July and 1 August revealed that the circulation consisted of a large elliptical low-pressure area with a center of calms and light winds in a cyclonic pattern 150 miles long, delineated by a squall line on the east and north and with strongest winds on the outside of the squall line. Eighteen hours after moving inland all closed isobars about the center had disappeared, but a large flat low-pressure area persisted in that part of the Western Gulf traversed by the storm until 5 August.

CHARLIE. Storm Charlie developed in an easterly wave as it moved under a stagnating upper westerly trough in the western Caribbean between Swan Island and the Yucatan Peninsula. The easterly wave, which can be followed from its appearance east of Antigua on 7 August, presented some indication of closed circulation as early as 9 August. However, continuity considerations deny the existence of a tropical cyclone prior to 0630Z 12 August. Once formed Charlie moved across the Yucatan Peninsula with little change in strength, intensified rapidly on moving into the Gulf of Campeche, reached hurricane force on the morning of 14 August, and at 1300 the next day moved inland over Tampico with maximum winds of approximately 110 mph. The anemometer at Tampico was destroyed when the wind reached 100 mph.

DOG-EASY. Storm Dog developed in an easterly wave which was first detected on 15 August moving across the Leeward Islands. Closed isobars could be drawn on the wave as early as 1230Z on 18 August, but a definite closed circulation could not be detected until 30 hours later when aerial reconnaissance reported a weak center at 23°6'N, 85°2'W at 2130Z, with maximum winds of 35 knots a short distance to the northeast. On 20 August two flights went out for reconnaissance. One located a definite calm center at 24°1'N, 86°5'W at 1530Z with maximum winds of 35 knots. The other reconnaissance flight located the center at 24°5'N, 87°5'W at 2215Z with maximum winds 35 knots and lowest pressure 1007.9 mb.

The following day two more reconnaissance flights were made. The first investigated the extrapolated position as determined from three

TABLE 1. TROPICAL CYCLONES OF NORTH ATLANTIC, 1947

NAME	DATE	PRESSURE WINDS MAX INTENSITY	DURATION IN DAYS STORM	HURRICANE	POSITION OF RECURVE	WENT INLAND	ORIGIN AND REMARKS
(1) Able (Extratropical)							
(2) Baker	31 July 2 Aug	44 mph	2	-	—	S of Brownsville, Texas	Easterly Wave
(3) Charlie	12-15 Aug	110 mph estimated	2	2	20° 5'N., 88°W 22°N., 97°W.	151230Z Tampico, Mexico	Easterly Wave
(4) Dog	19-25 Aug	66 mph at Galveston, Texas	5	-	—	Galveston, Texas 250030Z	Easterly Wave
(5) Easy	(Part of Dog)						
(6) Fox	8 Sep	51 mph gust at Pensacola, Florida	1	-	—	Biloxi, Miss. 081800Z	Easterly Wave
(7) George	4-19 Sep	160 mph at Abaco Is. 947.2 mb at Hillsboro light	8	8	26.8N 71.5W	Ft. Lauderdale, Fla. and New Orleans, La.	ITC near Cape Verde Islands
(8) How	210630Z 21-25 Sep	65 mph, 988 mbs	4	-	—	Cedar Keys, Fla 231230Z	Easterly Wave became extratropical S. Ga.
(9) Item	0030Z 6 Oct 6-8 Oct	65 mph	1	-	—	Brunswick, Ga.	Upper air stationary trough and zone of convergence
(10) Jig	(Probably Extratropical)						
(11) King	9-15 Oct	57 over Cuba, 150 estimated at Dry Tortugas (anemometer froze at 94), 92 at Hillsboro Lt., Estimated 95 at Savannah	3	5	20N 84W 32N 75W	Cuba, Cape Sable, Savannah	Easterly Wave moving into deep trough in Western Caribbean. Heavy rain fall over South Fla.
(12) Love	16-21 Oct	110 K, 961 mbs	2	3 (dropped as extratropical) at 34°N 70° 5'W.		—	Southern end of deep westerly trough with possibility of easterly wave supplying trigger action

previous fixes. Here SW winds were encountered but no center could be located. The plane turned to the north and 25 minutes later passed through a squall line with a 180° wind shift. Again no center was found; only a squall line with a 180° wind shift extending in a NW-SW direction.

The second plane, 9 hours later than the first, encountered similar weather but reported an area of no low clouds and calm sea within the squall line which resembled the eye found on the previous day. This was reported as the center of the storm with 1004.1 mb. minimum pressure, located at 28°1'N, 88°8'W at 2145Z. This report indicated an abrupt change in direction and speed of the storm and it was generally agreed that the storm continued on its new path, passing inland near Grand Isle, Louisiana, at approximately 1600Z on 22 August. Since no characteristic pressure falls or wind shifts were reported by coastal stations, the storm was assumed to have dissipated from the time of last observation by aircraft. However, at 1230Z, 23 August, the SS SINCLAIR, located at 28°3'N, 92°0'W reported a SE wind, force eight, and a pressure of 1004.1 mb., indicating that a tropical storm was centered a short distance to the southwest. This storm moved northwestward passing inland at 1200Z, 25 August near Galveston, Texas, where maximum winds of 68 mph were recorded.

At the time of their occurrence Storm Dog was considered to be the one that moved inland near Grand Isle, Louisiana, and Storm Easy was the designation for the one reported by the SS SINCLAIR which affected the Galveston area. However, post-season analysis makes it reasonably certain that the storm which struck Galveston is the same one that was located northwest of Cuba on 20 August, and that the purported dissipating storm moving inland on 22 August was actually a strong trough line associated with this storm.

Evidently the two reconnaissance flights on 22 August did not go quite far enough west to locate the center of the storm which had apparently accelerated and probably decreased somewhat in intensity since last observed on the 21st. During the following 24 hours it decelerated and intensified considerably as it underwent a slight recurvature to the left.

FOX. Storm Fox formed on an easterly wave which can first be detected on 1 September between Hispaniola and Puerto Rico. Evidence of closed circulation is not convincing until the 0030Z map of 8 September. Moving NW in an arc toward the WNW the storm moved inland near Biloxi, Mississippi, 18 hours later, with gusts to 51 mph recorded at Pensacola. A reconnaissance plane reported winds of 30 mph SSW of the center at 1600Z but did not go into the northern part of the storm since it was already over land.

GEORGE. Storm George was a Cape Verde Storm and ranks with great hurricanes of recent years. Mr. G. A. Mikulen of the Pan American Airways station at Dakar appears to have observed its origin and reported it as follows: "On 2 September 1947, the low aloft over the intertropical convergence zone was reflected on the surface and a disturbance developed, which, while still on land gave Dakar moderate E to NE winds. As soon as the disturbance moved out to sea, it deepened and picked up moisture, giving Dakar 85.4 mm. of rain on September 4th. This disturbance could be tracked moving westward until 1200Z September 5th when it moved over the Cape Verde Islands and was unreported until the SS ARAKAKA reported it on the night of September 10th at lat. 15°N., long. 49°W."

This reasonable average movement of 17 mph would bring the disturbance observed by Mr. Mikulan to the position reported by the SS ARAKAKA so there is little doubt that they are the same disturbance.

After the report from the SS ARAKAKA, Storm George was next reported 500 miles east of Guadaloupe at noon on 11 September by a reconnaissance plane. The storm moved west-northwestward to a point 250 miles east of Palm Beach where it hesitated and then resumed a course somewhat south of west, striking the Florida coast line near Ft. Lauderdale. Winds of 160 mph were recorded at Great Abaco Island, and 155 mph was reported at the Hillsboro Light near Pompano. It continued its westward course across Florida, arcing to the northwest across the Gulf of Mexico, and again passed inland near New Orleans on the 19th.

HOW. Storm How formed in an easterly wave which could be followed across the Caribbean for six days before closed circulation developed south of Cuba as the wave moved through the western Caribbean. Storm How then moved almost due north passing inland over Tampa, curving to the right and moving out to sea again north of Cape Hatteras as an extratropical low. Gusts to 70 mph were reported as the storm moved almost due north through Florida.

ITEM. Storm Item was not a truly tropical cyclone; neither did it possess the frontal structure of extratropical cyclones. From the 2nd of October the prevalence of shower activity, the wind field aloft and the cyclonic curvature of the isobars indicated an area of convergence over western Cuba, the Florida peninsula, and the northern Bahamas. There is also evidence of a semipermanent or stagnant trough over this area. At 0030Z on 4 October, a 24-hour pressure fall of 2 mb. was observed in central Cuba. Subsequent 24-hour pressure falls of 2 to 6.5 mbs. were observed in the same area during the next two days. By the evening of 5 October a deep trough had appeared in the surface isobars extending from the western Caribbean, through Cuba up to Charleston, South Carolina. By 0630Z on 6 October, closed circulation was evident over the Little Bahama Banks. At the same time a closed low appeared aloft over the western coast of Florida, centered near Tallahassee. The surface low moved northward, curved to the west passing inland near Brunswick, Georgia, and moved under the closed low aloft which had intensified and covered the area from Southern Florida to western North Carolina. The surface low moved into the Gulf of Mexico near Apalachicola, came to a halt and then moved back to the northeast, disappearing over Georgia.

KING. Storm King developed in the western Caribbean north of Panama as an easterly trough and moved into the deep trough extending southward from Storm Item. Its development was slow in the early stages, indicating that the ITC might have played a part in this area genesis but no evidence of the ITC being north of Panama at this time could be found. A closed isobar could be drawn in this area as early as 1230Z on 7 October. This low drifted slowly northwestward along the Nicaragua coastline during the next two days. Reports from Swan Island indicated that an easterly wave passed there at 0630Z on 7 October, and that a closed low from the south passed a short distance to the east of the station at approximately 0230Z on 10 October. Sixteen hours later the storm center was reported 180 miles north-northwest of Swan Island with maximum winds of 50 knots and minimum surface pressure of 1000 mbs. The storm moved northward curving to the right until it passed over Cuba, where it appeared to take an abrupt turn to the left and to accelerate until it reached Dry Tortugas. A maximum wind of 57 mph was reported at Batista Field. At Dry Tortugas the anemometer froze at 84 mph due to friction from lack of oil. The wind velocity continued to increase and the observer estimated that it reached 150 mph. At Dry Tortugas the storm appeared to make an abrupt turn to the right and struck the Florida coast near Cape Sable. This storm was observed by the Naval radar station at Key West which reported an area of strong echo to the NE of the storm center. As the storm passed over Florida it was preceded by spectacular thunderstorm activity and heavy rainfall. Baragrams show a double minimum, a weak one at the time of the thunderstorm with a short recovering before the minimum of the storm center itself. The wind also had a double maximum with light winds during and for a while after the thunderstorms. A maximum wind of 62 mph was reported by Miami but Hillsboro Light reported 92 mph.

The storm moved off the east Florida coast near Pompano and headed toward the northeast. Night reconnaissance flights using radar reported two centers on the morning of 14 October. One was reported about 150 miles off Norfolk, Va. and the other about 250 miles further south. Daylight mission later in the day could not find a definite center at the northern position but did find a storm of great intensity centered about 150 miles west of the position reported on the 13th. At 0230Z, 15 October, a night radar reconnaissance plane and the tanker SS SINCLAIR both reported a hurricane about 125 miles off Savannah, Ga. The storm moved inland south of Savannah at 1130Z, 15 October. Maximum winds at Savannah were estimated at 85 mph with gusts to 95. Post-analysis reveals that only one storm center existed during the period. The second center reported further north by radar was undoubtedly a continuation of the thunderstorm activity which preceded the storm center as it moved over Florida.

LOVE. Storm Love originated in a deep trough lying to the east of the Antilles, with the aid of the triggering action of an easterly wave. Ship reports indicated low pressure and possible closed circulation in this storm for several days. Reconnaissance flights into the area on the

15th and 16th of October indicated that a trough with possible closed circulation was moving into the Antilles but a closed low center was not definitely located until 1230Z on the 17th, about 100 miles north of San Juan, P.R., with winds of 28 knots and a pressure of 1002 mbs. The storm intensified rapidly, reaching hurricane strength within 24 hours. It recurved about 100 miles NE of Caicos Island and out into the Atlantic, and passed approximately 90 miles NW of Bermuda at 1600Z on the 20th. Beyond Bermuda the storm began to acquire extratropical characteristics.

2. Forecasting Storm Movement

The problem of forecasting the movement of tropical cyclones was approached by re-analysis of the storms of the 1947 season in the Atlantic area with special attention to the use of persistence or extrapolation methods, location of steering level, the verification given by use of the warm tongue or isotherm-steering principle, the degree of accuracy achieved by application of the theory of strongest wind or isobaric-channel-transport steering, and the effect on storm movement produced by the pressure-system distribution of the synoptic situation. Pertinent results of this study have been tabulated in Table 2.

It will be noted that only three computations were made of the technique of isobaric-channel-transport steering due to limited data available. One was made for storm How from 800-foot aircraft reconnaissance reports at 28° latitude. Computation from the sparse data in this case resulted in forecast movement to WNW at 5.3 mph, whereas the observed movement was NNE at 11 mph. Another computation for storm George at 1230Z, 15 September 1947, from 800-foot reconnaissance data indicated westward movement at 7.3 mph while the actual movement was figured as WNW at 11 mph. The other application to storm King on 10 October at 1800Z resulted in forecast of NNE at 7.6 mph which was verified by a storm movement of NNE at 7 mph.

Some verification of this method for one component of the storm movement was also obtained for storm Charlie. A reconnaissance flight into this storm on the afternoon of 14 August reported 80-knot wind from the north to the west of the center and 75-knot from the south to the east of the center. While the storm did not acquire a component to the south it did recurve to the left at this time from a direction of 310° to 270°.

Organization of reconnaissance flights to provide observational data for application of this technique will make further investigation of the strongest-wind-steering method possible during the 1948 season. This forecasting tool appears to promise well.

The application of the technique of warm tongue steering resulted in definite negative findings with reference to the 1947 storms. Actual existence of a cold tongue was noticed in study of some of the storms.

TABLE NO. 2 VERIFICATION OF TECHNIQUES FOR FORECASTING MOVEMENT

NAME OF STORM	PERSISTENCE FORECASTING	STEERING LEVEL	WARM TONGUE (ISOTHERM) METHOD	ISOBARIC-CHANNEL TRANSPORT METHOD	PRESSURE DISTRIBUTION
BAKER	Good if gradual curvature to west considered	None for first 12 hours. Winds from 5,000-30,000 ft. excellent thereafter	Negative (Limited Data)		High-pressure cell steered it WNW.
CHARLIE	Good until recurve to west	10,000 ft until westward curve; 15,000 ft thereafter	Insufficient data		Wedge of high pressure blocked north movement; caused westward path.
DOG-EASY	Excellent	Winds from 5,000-30,000 usable; 10,000 ft possibly best	Negative relation		Warm-core anticyclone to 30,000 ft over southwestern United States caused movement to WNW.
FOX	Excellent but storm short lived	20,000 ft winds	Inconsistent-no relation shown		High-pressure cell over Arkansas forced storm inland with short life history.
GEORGE	Good while strong E-W elongated high to north of storm. Good with a rate of movement over 10 mph	Early stage 40,000 ft. Later stage 60,000 ft winds	Negative relation	One tabulation gave close agreement in direction, but velocity inaccurate.	E-W orientated Bermuda High to north of storm coincident with westward movement. Low in SE U.S. coincident with movement of cyclone toward low
HOW	Good for most of storm history	30,000 ft winds	Inconclusive results, no definite relation	One tabulation gave WNW at 5.3 mph actual move was NNE at 11 mph	Deep anticyclone to east between Florida and Bermuda and approach of pronounced trough from west gave steering pattern to north and later to northeast
ITEM	Good in first 12 hrs but not thereafter	Winds up to 40,000 ft reliable until curve westward 5,000-20,000 ft winds thereafter	No relation found		Trough to 40,000 ft steered storm north until Bermuda high circulation intervened and moved it westward.

TABLE NO. 2 VERIFICATION OF TECHNIQUES FOR FORECASTING MOVEMENT (CONT'D)

NAME OF	PERSISTENCE FORECASTING	STEERING LEVEL	WARM TONGUE (ISOTHERM) METHOD	ISOBARIC-CHANNEL TRANSPORT METHOD	PRESSURE DISTRIBUTION
KING	Definitely not usable	Formative stage 20,000-25,000 ft winds Mature stage 25,000-30,000 ft winds Indefinite in latter periods of storm	No consistent relation	One tabulation with excellent verification	Trough from storm Item moved storm north and filled. Fast moving trough followed and influenced storm movement until high pressure curved its path to west
LOVE	Good except during recurve	10,000-18,000 ft winds	No relation except during later part of storm		Semi-permanent Atlantic anticyclone controlled storm movements

It must be admitted that the radiosonde data are in most cases insufficient to make reliable analysis of the mean temperature field outside the continental United States.

Study of the techniques of selecting a steering level for tropical cyclones shows that there was a definite relationship between the upper-wind flow and the paths of movement of the tropical cyclones of the 1947 season but selection of a particular level for any certain storm is impossible. When the direction of flow was constant up to 30,000 feet the situation was simplified but such distribution was noted only twice (Baker, Dog-Easy).

3. Forecasting Change of Intensity

In studying the problem of forecasting changes of intensity of tropical cyclones, the storms of the 1947 season were examined for the effects of the rate of storm movement, slope of the cyclone axis, geographical location, and the effect of the synoptic situation. Special attention was given to westerly and easterly troughs, warm and cold advection aloft, blocking high-pressure cells, and movement into the region of extratropical fronts. Table 3 presents a summary of this study.

Definite relation between slow movement and storm intensification is evident. The relation of weakening with increased rate of storm advance also is to be noted.

In storm Item increase of average speed from 15 to 28 mph gave no appreciable change of intensity, but it is thought that the increased rate of movement counteracted warm-air advection during the same period with resulting lack of intensity change.

Storm Love continued to deepen during a period of increased average rate of movement from 12 to 16 mph but the trough of low pressure under which the storm moved is considered to have produced the increased intensity.

Geographical location of the storms illustrates the effect of the storm dissipation when moving inland except when the expanse of land traversed was relatively small, as in the cases of storms George and King which reintensified after moving across southern Florida, and storm Charlie which crossed the Yucatan Peninsula during its formative stages. Only the last storm of the season (Love) continued its movement over water to middle latitudes where it took on extratropical characteristics because of its geographical location.

Results of comparative relation of cyclone axis and storm intensity are inconclusive concerning the relationship between change of slope and change of intensity. The preponderance of westward slope of storm axes would seem to add evidence to the theory that such slope is related to tropical storm development in the Caribbean and Atlantic areas.

TABLE NO 3 FACTORS IN FORECASTING INTENSITY CHANGE

NAME OF STORM	RATE-OF-MOVEMENT EFFECT	SYNOPTIC-SITUATION EFFECT	GEOGRAPHICAL-LOCATION EFFECT	SLOPE-OF-CYCLONE-AXIS EFFECT
BAKER	15 mph: storm intensified. 20 mph: storm weakened while also moving over land	Trough 10,000-20,000 ft caused intensification. Steering high moved storm inland. Cold air advection aided dissipation	Short life over Gulf of Mexico before moving inland with dissipation	Westward slope while nearing land and intensifying (limited data)
CHARLIE	17 mph slowed to 8 mph: storm intensified	Moved under westerly trough and intensified. Blocking high caused retardation and intensification	Passage over Yucatan Peninsula had little effect in formative stages. Intensified over water. Dissipated after moving inland	Westward slope over Gulf and intensifying
DOG-EASY	Indefinite speed. Retarded movement resulted in slow intensification	Blocking high caused retardation and intensification. Movement into low pressure area caused added intensification approximately 250 miles offshore	Intensified while moving in Gulf of Mexico. Dissipated after moving inland	Westward slope throughout storm history
FOX	Average 8 mph movement during short life history	Intensified under trough 5,000-30,000 ft.	Dissipated rapidly after moving inland	Westward slope throughout storm history
GEORGE	20 mph slowed to 15 and 4 mph with intensification. Increased speed to 15 mph with slightly decreased intensity	Bermuda High steered storm movement over tropical waters with intensification. Anticyclogenesis in western U.S. gave blocking effect and intensification	Intensified during movement over South Atlantic. Slight diminution passing over Florida. Regained intensity over Gulf of Mexico. Dissipated after moving inland	West and northwestward slope during most of storm history. Short period of south and east slope. No relation to change of intensity found.
HOW	Intensified with slow movement of 12 mph. Decreased over land moving 18 mph	Intensified on movement into trough in east U.S.	Increased over water Decreased over land	Westward slope during intensification and decrease
ITEM	15 mph movement gave intensification, 28 mph movement caused no change of intensity	Intensified under trough aloft. Warm air advection during rapid movement with no intensification	Movement inland caused rapid decrease	Westward slope

TABLE NO 8 FACTORS IN FORECASTING INTENSITY CHANGE (CONT'D)

NAME OF STORM	RATE-OF-MOVEMENT EFFECT	SYNOPTIC-SITUATION EFFECT	GEOGRAPHICAL-LOCATION EFFECT	SLOPE-OF-CYCLONE-AXIS EFFECT
KING	12 mph decreased to 6 mph caused intensification, increase to 13 mph decreased storm. Drop to 8 mph-sudden intensification, 15 mph-slight decrease in storm strength	Trough associated with storm Item intensified storm. Trough filling caused weakening until movement into following trough which moved out rapidly, causing storm steering west by high	Movement over land weakened storm slightly. Reintensified over water. Dissipated after moving inland	Southeast slope in early stages. Indefinate thereafter
LOVE	Slow movement 12 mph intensification, 16 mph continued to deepen, 22 mph-weakening	Warm air advection caused intensification-also move into trough caused deepening	Northward movement into middle latitudes caused extratropical characteristics and weakening	Insufficient data

As in the forecasting of storm movement, so in determining changes of intensity, the effect of the current synoptic situation is of the utmost importance. The influence of advection aloft and of low-pressure troughs was noted above. Blocking anticyclones with retardation of storm movement and consequent storm intensification were important features of storms Baker, Charlie, Dog-Easy, George, and King.

4. Problems Requiring Basic Research

The post-season analysis of the 1947 storms reveals definite weaknesses in the cyclone theories which have been developed to date, and the existence of hurricane forecasting rules and practices which have little or no theoretical support. This lack of theory makes hurricane forecasting extremely difficult since observations themselves are at a minimum. Scanty observations can be placed into a reasonable analysis and an accurate forecast made only where the framework of the model and its behavior have been previously determined by theory or by statistical composition of past observations. The latter approach to the problem can be and is being made by this office. The development of the underlying theory, however, is beyond the mission and capabilities of this office. For this reason the following problems requiring research are recommended for assignment to institutions equipped and staffed to perform such work:

a. Development of a basic cyclone theory which will explain the intensification of waves in the tropical easterlies which slope westward with height, and move with a speed less than that of the air-stream in which they are embedded.

b. Re-evaluation, from a theoretical standpoint, of the ideas listed below, now commonly used for forecasting the movement of tropical cyclones:

(1) Tropical cyclones move 30° to the right of the representative wind at 10,000 feet in the storm area.

(2) Tropical cyclones move in the direction of the wind directly above the closed circulation.

(3) Tropical cyclones move in the direction of the mean isotherms (with colder air to the left) of the airmass in which they are embedded.

(4) Tropical cyclones move in the direction of the strongest wind on any one isobar within the cyclonic circulation after proper correction is made for the difference in the coriolis force in the different parts of the storms.

c. Determine whether the weaknesses of the Caribbean sferics network are due to incomplete observations (i.e. not covering a long enough period to record all possible fixes), rather than equipment incapable of detecting all areas of atmospheric turbulence and electrical discharges.

d. Blueprint a seismographic network which will record the amplitude and azimuth of the microseisms originating in the Caribbean, Gulf of Mexico, and adjacent Atlantic Ocean; eliminating, in so far as possible, the effects of local earth structure and microseismic barriers.

✓e. Develop a radar set which can be installed in B-29 aircraft with an airborne range of at least 200 miles, and which can detect precipitation and clouds of vertical development without excessive attenuation.

APPENDIX I: OUTLINE OF DATA TO BE COMPILED.

Determine following for each map time or when data available:

Storm Position -- Geographical coordinates;
Direction and Speed -- From positions 6 hours before and after map time;

I. INTENSITY

A. At Surface

1. Maximum wind -- how determined
2. Surface pressure -- how determined
3. Radius of force 12 winds (greater than 75 mph) to N, E, S, and W at center
4. Radius of force 6 winds (greater than 25 mph) to N, E, S, and W at center
5. Diameter and pressure of largest closed isobar on surface chart

B. At 700 mb

1. Maximum wind reported and distance and direction from center
2. Diameter of largest closed isobar

C. At 500 mb

1. Maximum wind reported and distance and direction from center
2. Diameter of largest closed isobar

D. Change in intensity during last six hours - increased, decreased or none

E. Element responsible for change in intensity

1. Rate of movement
2. Synoptic Situation
   a. Westerly or easterly trough
   b. Temperature advection
   c. Blocking highs
   d. Movement into vicinity of extratropical fronts
3. Movement over land area
4. Geographical location
5. Slope of cyclone axis (Principle of Krasner & Landon)

II. DIRECTION OF MOTION

A. Steering - Direction and Speed of representative wind in storm area at following elevations:

1. Surface
2. 850 mb, 5,000 Ft.
3. 700 mb, 10,000 Ft.
4. 500 mb, 18,000 Ft.
5. 300 mb, 30,000 Ft.
6. 200 mb, 40,000 Ft.
7. 100 mb, 55,000 Ft.
8. The steering wind is sometimes considered to be the wind in the storm area immediately above the top of the storm or cyclonic circulation. Therefore, study all winds aloft in the storm area which happen to extend above cyclonic circulation. Previous studies indicate that the winds to the west of the storm are very important.
9. Mean Isotherm Direction - cold air to left (Principle of Simpson)
10. Strongest wind steering - (Principle of Major Moore)

    a. E-W Velocity
    b. N-S Velocity
    c. Resultant direction and velocity (level used)

B. Element responsible for best steering wind

C. Indicants and counter indicants for persistence forecasting

1. Latitude
2. Synoptic situation
3. Speed of movement

III. GENERAL SYNOPTIC STRCUTURE

A. Height of Cyclonic Circulation

1. From pibals or rawins which appear to extend above the storm circulation, consider direction and distance of reporting station from center.

2. Using central surface pressure and surface temperature in storm area follow a moist adiabat to the point of intersection with the nearest reported sounding.

B. Wind Field

1. Angle between wind and isobars at various gradients
2. Variation of strength of cyclonic circulation with height.
3. Variation of extent of cyclonic circulation with height
4. Presence or absence of air diverging from the storm area at high levels as shown by rawins or cloud directions
5. Variation of wind speed with distance from the center

C. Temperature Field

1. Surface temperature field -- does surface air converge isothermally?
2. Evidence of warmer air in core of cyclone. Record temperature rise and altitude reported by Recon.
3. Plot sounding made in eye and compare with nearest reported Raob.

D. Type, Distribution and Extent of Clouds

E. Distribution of Vertical Velocities.

1. Prepare composite map of individual storms using distribution of clouds of vertical development and recon reports of turbulence.
2. Does distribution of vertical velocities change with life of the storm?
3. Does it remain the same with reference to direction of motion or with reference to compass directions?

F. Distribution of Precipitation

1. Prepare composite chart of rain reported by aircraft, ships and surface stations for individual storms.
2. Does distribution change with life cycle of storm?
3. Does distribution remain the same with reference to compass direction?

G. Slope of Axis

1. Study variation of wind with height in storm area -- slope is to the left and perpendicular to the shear with height?
2. Do recon positions (either visual or radar) show systematic difference between 10,000 and 500 feet?

H. Shape of Surface Circulation

1. Were isobars and streamlines circular with a different center or eye or was the circulation diffused with no definite center?

2. If isobar and streamlines were not circular in periphery but became so in the center, above what speed did they become so?

IV. SYNOPTIC ELEMENTS RESPONSIBLE FOR GENESIS AND DEVELOPMENT OF TROPICAL CYCLONES.

A. Did the storm originate:

1. In the Cape Verdes (probably in the ITC) off Africa?
2. In an Easterly "Wave" -- spontaneously or as, or shortly after, it passed a slow moving or stagnant trough in the westerlies?
3. In the Western Caribbean when the ITC was north of Panama and a triple point was formed with either a westerly or easterly through stagnating in the area?

B. If an Easterly "Wave" was involved in the genesis, follow its life history watching for:

1. A change in slope with height from rearward to forward as shown by

   a. Pibals
   b. Shower activity moving from behind to ahead of the trough

2. A reversal of temperature from warmer ahead of the trough to warmer behind the wave.

3. When the tropical cyclone formed did it move in the direction of motion of the easterly wave front or to the right of that direction?

C. Study Raobs in area where cyclone formed for several days prior to genesis watching for constant increases in:

1. Lapse rate
2. Height of top of the moist layer (trade inversion)
3. Mixing ratio and/or humidity at fixed levels
4. Temperature

V. VALUE OF SFERICS REPORTS

Check Sferics maps with continuity map of storm and synoptic elements responsible for its genesis. Record the following information for each map time:

1. Total number of sferics fixes by type
2. Number of fixes by type originating from storm or its precoursers
3. Number and type of definite synoptic elements other than the storm and its precoursers which do or should give sferics fixes

VI. VALUE OF MICROSEISMIC REPORTS

A. Make a time graph for each microseismic station of the following elements:

1. Distance of tropical cyclone and/or precoursors from microseismic station
2. Amplitude of microseisms
3. Period of microseisms

If there is not a direct inverse correlation, it should be explained by changes in intensity of the storm or by microseismic barriers.

B. Where azimuth angles are reported plot the track of the storm marking positions at six hourly intervals and draw azimuth angles from reporting stations indicating time of microseism. Intersection of azimuths with track indicates position at time of microseism. Check this with time storm was actually at that position. If two or more azimuths are reported, intersection of azimuths with each other also gives a fix which can be compared with the other two.

C. Check time of increase of microseism amplitude with time of genesis of a tropical storm. Do microseisms indicate possibility of a cyclone before it can be detected by other means?

VII. ANALYSIS OF THE PAST HURRICANE FORECASTING PERFORMANCE WITH THE VIEW OF THE SELECTION OF THE BEST TECHNIQUES.

A. Forecasting storm movement

1. Persistence forecasting
2. Determination of steering level
3. Warm tongue and isotherm steering
4. Strongest wind or isobaric channel transport steering
5. Effects of pressure distribution

B. Forecasting changes in Intensity

1. Rate of movement
2. Synoptic Situation (Refer to outline I E2a,b,c,d)
3. Movement over land
4. Geographical location
5. Slope of cyclone axis

Summarize the forecasting methods used in the storms for which you are responsible, indicating the success or failure achieved. Specifically indicate which of the above methods might have been employed and those which would not have given the correct forecast with reference to the storms on which you are reporting.

Note outstanding examples as to date, time, and related data. Prescribe illustrative material for such examples in detail.

VIII. FILE OF REFERENCE DATA

A. List available material on file on the Air Force Hurricane Office

1. Raw data
2. Recon reports
3. Analyzed charts and cross sections
4. Reports or summaries
5. Photographs

IX. RECONNAISSANCE FINDINGS

A. From reports on Hurricane Reconnaissance flown by 373d Recon Sqd. and Navy, 1947 season, list and evaluate:

1. Findings and conclusions provided by reconnaissance with reference to the specific storms for which you are responsible.
2. List of any of your own findings and conclusions concerning such specific reconnaissance.

APPENDIX II DATA FOR A GENERAL SYNOPTIC

STORM	HEIGHT OF CYCLONE CIRCULATION	WIND FIELD	TEMPERATURE FIELD
Able	Due to the fact that storm Able did not develop into a tropical storm, synoptic		
Baker	First 30 hours of life below 20,000' then after 42 hours up to 25,000' and down to 20,000' upon going inland	Isobars are mostly parallel to winds except where winds are less than 10 mph, they are variable. Strongest winds (Force 6) are near the center and almost due east up to 225 miles from center. The strength of the cyclonic circulation remains almost constant to 25,000'. The area of closed cyclonic circulation remains almost constant to 25,000'. The area of closed cyclonic circulation from the surface to 10,000' is almost doubled from 10 to 20 thsnd. There is no evidence of diverging air aloft. The area of strongest winds are in the direction of N and E from the center. Lightest winds are west of the center.	Insufficient data near center to determine whether or not surface air converges isothermally. No evidence of warm air in the core. Isotherms show warmest air in NW quad. with coldest air in the SW and SE quadrants.
Charlie	Lack of data over Gulf area. Evidence of circulation to 15,000 ft. from pibal reports. No data above that level available	1. Greatest cross isobar in the NE and SE quadrants. Least in the NW quadrant. 2. Surface cyclonic circulation: average diameter of 270 miles. 3. 700 Mb cyclonic circulation: average diameter 450 miles. 4. 500 Mb cyclonic circulation: average diameter 450 miles. 5. Average distance of Beaufort force 6 and force 12 from center: Force 12 (average of 2 Obs): N- 97 miles, S- 60 miles, E- 70 miles, W- 85 miles Force 6 (average of 12 Obs): N-135 miles, S- 86 miles, E- 90 miles, W-130 miles 6. Intensity of cyclonic circulation: unable to determine due to lack of data.	Coldest temperature at center of storm with cold tongues extending from center into NE and NW quads. A trapped cold area in SW quadrant. Warmest air in the SE quadrant and in the NE quadrant 350 miles from the center.

MODEL OF THE TROPICAL CYCLONE

CLOUD DISTRIBUTION TYPE	CLOUD DISTRIBUTION EXTENT	DISTR OF VERT VEL CHANGE WITH LIFE CYCLE	DISTR OF VERT VEL CHANGE WITH COMPASS DIRECTION	PRECIPITATION DISTRIBUTION	SLOPE OF AXIS	SHAPE OF SURFACE CIRCULATION
model is not submitted.						
Vertically developed low clouds	In all quads with maximum in NW and NE quads. Rest in SW quad.	Light intermittent turb reported on 31 JULY with moderate intermittent on 1 August. More tstms reported on 31 July	Vertical velocities in all quads with more tstms in SW and the least vertical velocities in the SE quad.	Heaviest precip in SE quad with showers and intermittent rain in all quadrants. Least rain in the SW quad.	With very little data a Northward slope is indicated	Center isobar and wind field is roughly elliptical in shape with major axis in a NNE-SSE direction. Isobars are more tightly packed to the N, NE and NW. Least gradient to the SE and SW
Middle clouds	Greatest amount of middle clouds in SE quad, and AS in all quads least in SW.					
High clouds	High clds in all quads. greatest in NE and NW. Least in SW					
Vertically developed low clouds	All quadrants of storm. Maximum reported in NE quadrant with second maximum in SW quad. Strongest concentration of CUNB extends southward from center for a distance of 300 miles in NE quadrant.	Increase in turbulence with storm development and also at point where it started to recurve.	Lgt to moderate 150 miles from center. Severe 60 miles outward from center in NE quad and 40 miles outward in NW quadrant	Thunderstorms and showers in all quadrants at a radius of 500 miles from center. Steady precipitation extends from center for 60 miles in NW SW and SE quads. In NE quadrant, radius of squally weather extended outward 120 miles and heavy precip 90 miles radius from center.	Insufficient data but small indications of a westward slope	The first 3 or 4 closed isobars are circular throughout the life of the storm, with the outer isobars becoming elliptical in a NE-SW direction in the later stage of the storm.
Middle Clouds	AS and AC in all quads. AS predominate in NE and SE quads. Fewest in NW quad.					
High Clouds	CS and CI extend outward to 500 miles in NE and NW quadrants. Few reported in SE and SW quad.					

DATA FOR A GENERAL SYNOPTIC MODEL

STORM	HEIGHT OF CYCLONE CIRCULATION	WIND FIELD	TEMPERATURE FIELD
Dog- Easy	20,000 ft. during first two days becoming 30,000 to 40,000 thereafter until end of the storm	1. Cross isobar flow in all quadrants with greatest amount occurring in the NE and SE quadrants. 2. Surface cyclonic circulation: average diameter 220 miles. 3. 700 Mb cyclonic circulation: 4. 500 Mb cyclonic circulation: average diameter 300 miles estimated. 5. Average distance of Beaufort force 6 wind from center: (Average of 8 observations) N-103 miles S- 65 miles E-120 miles W- 72 miles 6. Intensity of cyclonic circulation: intense to 10,000 first two days and increasing to 30,000 feet thereafter.	Relative cold air at center with coldest air in the NE quadrant 100 miles from center. A small area of warm air separates this wedge from a secondary wedge of cold air to the SE. Small closed areas of cold air in NW and SW quadrants approximately 150-200 miles from center. Warm air in entire SE quadrant with warm air from center to 75 miles in the NE and SW quadrants. Cold air from center to NE quadrant Warmest air observed is 300 miles north of center in the N quadrants.
Fox	Up to 10,000' after first 12 hours then to 20,000' 6 hrs later then 16,000 upon going inland.	Winds are light and variable crossing isobars at all angles except in area of 80 miles radius from center where winds are practically parallel to isobars. Cyclonic circulation with height increased gradually to 8-10 thsnd then decreasing to 20,000 and remaining light and variable at higher levels. The area of closed cyclonic circulation remained almost the same size at all levels. There is no positive indication of diverging air. The winds are less than force 4 for an area of 700 miles around the storm except within a radius of 80 miles they are from force 4 to 6.	The surface air appears to converge isothermally. No evidence of warm air in the cyclone but data available is not conclusive as no sounding was made in the center.

OF THE TROPICAL CYCLONE (CON'D)

CLOUD DISTRIBUTION TYPE	EXTENT	DISTR OF VERT VELOCITIES CHANGE WITH LIFE CYCLE	CHANGE WITH COMPASS DIR	PRECIPITATION DISTRIBUTION	SLOPE AXIS	SHAPE OF SURFACE CIRCULATION
Vertically developed clouds	All quadrants of storm, maximum number and coverage reported in NE quadrant	Increase in turbulence with storm development	Light to moderate intermittent extending outward 175 miles from eye. Heaviest turbulence reported was 60 miles from the eye in NE quadrant	Thunderstorms and showers in all quadrants at a radius of 500 mis. from center. Extent of "eye" was 30 miles radius with no rain reported in this area. Steady precip extended outward for 175 miles from the outer ring of the "eye" in the NE quadrant. The most intense and greatest number of thunderstorms occurred in NE quadrant.	Slope was to the west throughout the history of the storm.	The innermost two isobars remained circular throughout with the remaining isobars assuming an elliptical shape in a NE-SW orientation during the latter stage of the storm.
Middle clouds	AS and AC in all quadrants. Maximum reported in NE quadrant and minimum reported in SE quadrant					
High Clouds	CI and CS extend outward for 500 miles in all quadrants					
Vertically developed clouds	In all quadrants with large coverage in NW, SE, and NE quads. Very few in SW quad.	Only turbulence reported was moderate intermittent and this was 120 miles southwest of center. This was after storm moved inland. No evidence of severe turb at any time.	Most turbulence and vertical velocities is away from the center and in all quads with less in the SW	Practically all precip was continuous within miles of center in the NE and NW quads.	Slopes to NW from an analysis of the wind shear	The pressure field is weak showing up only as a trough line in composite isobars drawn for the period of the storm.
Middle clouds	AS and-AS most in NE and SE quads. very few in SW quad.					
High clouds	In all quads; closest to center in NW quad and furthest from center in NE quad.					

DATA FOR A GENERAL SYNOPTIC

STORM	HEIGHT OF CYCLONE CIRCULATION	WIND FIELD	TEMPERATURE FIELD
George	During early stage 35,000 ft. During later stage 50,000 ft.	More cross-isobar flow indicated in SE quadrant. Cross-isobar flow about the same on the outer periphery of storm as it is near the center. Strong cyclonic circulation in indicated to the "top" of the storm, however circulation gradually diminishes aloft above 5,000 ft. Hurricane winds in general extend out to about 125 miles from center	Early stage: Warm air near the center, warm air northeast of the center, and warm air at lower latitudes south of the storm. Later stage: Small area of warm air to the northeast of the center with a large arew of cooler air to the north and northwest of center. The area of cold air is caused by increased precipitation evaporated and increased adiabatic cooling. Surface air apparently converges isothermally toward the center.
How	25-30,000 Ft.	More cross-isobar flow indicated in the SE quadrant of the storm. Cross-isobar flow also seems to be more prevailant near the center of the storm. Strong winds are in general within 200 mile radius. Cyclonic circulation extends up to 25-30,000 ft. with an apparent decrease in circulation intensity aloft above 5,000 ft.	Warm air is present in the center and on the northeast side of the storm. Surface air seems to converge isothermally toward the center.

MODEL OF THE TROPICAL CYCLONE (CON'D)

CLOUD DISTRIBUTION TYPE	CLOUD DISTRIBUTION EXTENT	DISTR OF VERT VELOCITIES CHANGE WITH LIFE CYCLE	DISTR OF VERT VELOCITIES CHANGE WITH COMPASS DIR.	PRECIPITATION DISTRIBUTION	SLOPE OF AXIS	SHAPE OF SURFACE CIRCULATION
Vertically developed lower clouds	All quadrants of storm in general, most pronounced in an area 300 mi in diameter centered about 125 mi NE of center.	Increase in turbulence with storm development	Turbulence all quads mostly within 200 mis. radius (more Recon obs taken near center of storm) Reports indicate slightly more turbulence in Srn sector Vertically developed clouds in all quads, most pronounced in NE quad.	Area 300 mi. in diameter, centered 125 mi NE of center contain heaviest and most continuous precip. Squalls and tstm activity all directions out to 400-500 miles.	In general slope to the W and NW, particularly during periods of intensification.	Isobars and streamlines are quite circular out to 250 mi. from center however, in general, ar slightly "bellied" out to the south.
Middle cloud	AC and AS in all quads with AS being predominant in NE quadrant.					
High clouds	CI and CS in all quads out to 500 mis.					
Clouds of vertical development	All quads of storm. Less reported in NW quadrant than others.	Increase in turbulence when storm developed	Vertical vel. about the same in all quads.	Area of heaviest pcpn is about 400 mi in dia and is centered about 200 mi N of storm center. Squall, shower and thunder activity out to about 300 mi fr center.	Variable and not indicative	Isobars and streamlines although slightly "bellied" out to the south, are quite circular out to about the force five winds, but especially circular out to the for· seven wind
Middle clouds	A C and AS reported in all quads with thin AS being predominant in NE quad.					
High clouds	CI and CS in all quads out to about 400-500 miles					

TABLE 4: DATA FOR A GENERAL SYNOPTIC

STORM	HEIGHT OF CYCLONE CIRCULATION	WIND FIELD	TEMPERATURE FIELD
Item	1st 6 hrs 14,000' 2d 6 hrs 60,000' remaining 18 hrs to 40,000' By RAOB analysis 29,000'	In all quadrants within 100 miles of the center the winds flow across the isobars at almost a 10° angle. In the NW and NE quadrant the winds flow across the isobars at angles up to 90° and averaging 60°. The flow is almost parallel in the SW and SE quadrants. In the first 12 hrs the winds aloft increase to about 10,000' then increase slowly or remain the same to 40,000'. The extent of closed cyclonic circulation averages about 400 mi below 5,000' and expands at higher levels to 900 mi. The wind is almost parallel to the isobars at all levels above the surface except for slight indications of divergence in the NW quad. at levels above 5,000'. The strongest area of winds are in the NW to 100 to 250 miles from the center. The greatest area of force two winds are in NW quad.	The surface air apparently converges isothermally. The warmest air is in the SE quadrant, the coldest in the NW.
Jig	Probably Extratropical		
King	1. Pibal and Rawin 16,000 to 40,000 ft. life of storm 2. Miami Raob approx 60 mi ENE of center indicated height of cyclonic circulation as 29,000. Other examples well above 30,000 ft but 125-210 miles away from center.	1. Greatest cross isobar in NE and SE quadrants, varied 30°-45°. Less than 30° in NW and SW quadrants. 2. Intense from surface to 16,000 feet formative stages increasing to 10,000 ft. in its mature stage. 3. Surface cyclonic circulation radius 23 miles, diameter 462 miles. 700 Mb cyclonic circulation radius 190 miles, diameter 380 miles. 500 Mb cyclonic circulation radius 232 miles, diameter 464 miles. 4. Negative 5. Average distance of Beaufort force, 6. or greater from center of storm N-131 miles NE-136 miles E-171 miles SE-179 miles S-139 miles SW-119 miles W-120 miles NW-144 miles	1. Surface air does not converge isothermally 2. There is evidence of warmer air in core of cyclone. Temperature field not consistent. Some evidence of cold air in center of storm 3. No sounding available

MODEL OF TROPICAL CYCLONE (CONT'D)

CLOUD DISTRIBUTION TYPE	EXTENT	DISTR OF VERT CHANGE WITH LIFE CYCLE	VELOCITIES CHANGE WITH COMPASS DIR.	PRECIPITATION DISTRIBUTION	SLOPE OF AXIS	SHAPE OF SURFACE CIRCULATION
Vertically Developed	Greatest area in SE quad with next greatest in NE In SE clouds extend to 675 mi. Least in NW quad.	Most turb reported after 12 hours of development	Severe in NE quad after 12 hours. No other reports but clouds indicate max vertical velocities in NE and SE quads from center to 275 miles.	Heaviest precip in NE quad center to 350 mi. Largest area of precip in NW quad center to 400 miles. Least precip in SE quad and SW quad quad and mostly showers. Closed rain to center in any quad is 80 miles.	Indication of little available data point to a NW-ward slope	1st 2 center isobars are almost circular but the rest are becoming very eliptical with major axis NNW-SSE and isobars opening to the south with very tight gradient in SE quad with SW second in least.
Low clouds	Almost equal distribution in all quads					
Middle Clouds	Greatest in NE and NW (AN) quads. Least in SE					
High clouds	Extend outward to 660 miles in all quads. Most observed close to center in SE quad.					

All types	Generally all quads. Intense in NE quad with secondary intensity SE quad. Least extent SW quad. This applies to all layers	Vrbl according to time of advance of storm and speed of movement. Changes with life cycle of storm increased turbulence with life cycle, mainly in NE quadrant.	Changes with reference to direction of motion Turb vrbl mainly NE quadrant.	Changes with life cycle of storm and does not remain the same with reference to compass direction. Most intense precip NE quadrant, generally in all quads.	Variable and not indicative On slopes investigated slopes were SE indicating filling, actually storm deepened slowly and at Dry Tortugas area deepened suddenly	Isobars and streamlines circulate with a definate center. Isobars and streamlines not circular in the periphery of the storm but became so toward the center with a wind speed of Beaufort force 6 or greater.

DATA FOR A GENERAL SYNOPTIC

STORM	HEIGHT OF CYCLONE CIRCULATION	WIND FIELD	TEMPERATURE FIELD
Love	Reporting stations not very close to storm. Evidence of cyclonic circulation to over 30,000 ft. Then some lowering to below 30,000 ft. in later stages when passing Bermuda	1. Greatest cross isobar flow occurred in both southern quadrants although there was a tendency for the flow to follow the isobars in the SW quad in the last period of the storm. 2. Force ten winds extend to 75 miles in all quadrants except SE. Beaufort 12 winds over 25 mile radius near end of storm. 3. Greatest extent of cyclonic circulation (Beaufort) 400 miles. 4. 700 Mb cyclonic circulation of diameter of 400 miles. 5. 500 Mb cyclonic circulation of diameter estimated 275 miles.	1. Surface air shows some evidence of isothermal convergence with definite evidence on 19 or 20 October. 2. The warmest air is confined to the southwest quadrant. 3. Temperature readings in the eye show 1-2 degree temperature rises with respect to surrounding air.

MODEL OF TROPICAL CYCLONE (CONT'D)

CLOUD DISTRIBUTION TYPE	EXTENT	DISTR OF VERT VELOCITIES CHANGE WITH LIFE CYCLE	CHANGE WITH COMPASS DIR.	PRECIPITATION DISTRIBUTION	SLOPE OF AXIS	SHAPE OF SURFACE CIRCULATION
Low clouds	Evident in all quadrants but, to a minimum in the SW. Extent of this type cloud indefinite	In its early stage, these and vertical velocities were characteristic of the NW and SE quadrants. In its later stage these characteristics remained in the NW and SE quads but also spread to the SW quad. The NE had a definite lack of these characteristics.	The early cycle of this storm is prior to change in direction while the latter stage is after change. Therefore the adjacent information is true of this topic.	In its early stage, precip was predominant only in the northern quads with the NE a bit more extensive. In its later stage, the precip spread to all four quads and appeared to be almost equal in its distribution.	Insufficient data to thoroughly investigate this point.	Circulation had a definite "eye" The shape of the circulation was very much assymetrical. In its early stage, it was elliptical with axis WNW-ESE. In its recurvature period, it was bellied out in the northern quadrants. In its final stages a definite shape could not be decided on.
Middle clouds	AC and AS most evident in NE and NW quads. This type cld evident to a good degree in SE quadrant in latter stages of the storm.					
High clouds	Evident in all quads with max in northern sectors. Minimum in SW. 500-600 miles ahead of storm.					

APPENDIX III: REFERENCE MATERIAL

A working library of reference material for tropical analysis and hurricane forecasting is being collected at the Air Force Hurricane Office. The following list shows the items available and reviewed during the first off-hurricane season operation: (Note BAMS = Bulletin of the American Meteorological Society.)

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HQ., AIR WEATHER SERVICE, WASHINGTON, D.C. (TR-105-37)

OFF-SEASON OPERATIONS OF THE AIR FORCE HURRICANE OFFICE 1947-1948 (AND APPENDIXES I, II, III)

BURGNER, N.M.; DOTSON, V.D.; ELLSAESSOR, H.W. AND OTHERS
JULY'48 43PP DIAGR, CHART

METEOROLOGY - RESEARCH
STORMS - TRACKING
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METEOROLOGY (30) 2
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ABSTRACT:

A study was made of certain features of the hurricane-warning service between the end of the 1947 hurricane season and the beginning of the 1948 season as they concern the USAF and Army requirements. Three specific operational problems were studied: Improved utilization of aerial reconnaissance in hurricane forecasting, analysis of the past hurricane-forecasting performance, and supplemental analysis of tropical storms of the preceding season. The group was advised to concentrate on forecasting the direction of motion of tropical cyclones, forecasting changes in tropical storm intensity, and determining the general synoptic model of a tropical cyclone. The principal results of the study conducted during the period of the first off-season operation are presented.

DISTRIBUTION: Copies of this report obtainable from CADO.

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