Weatherwise

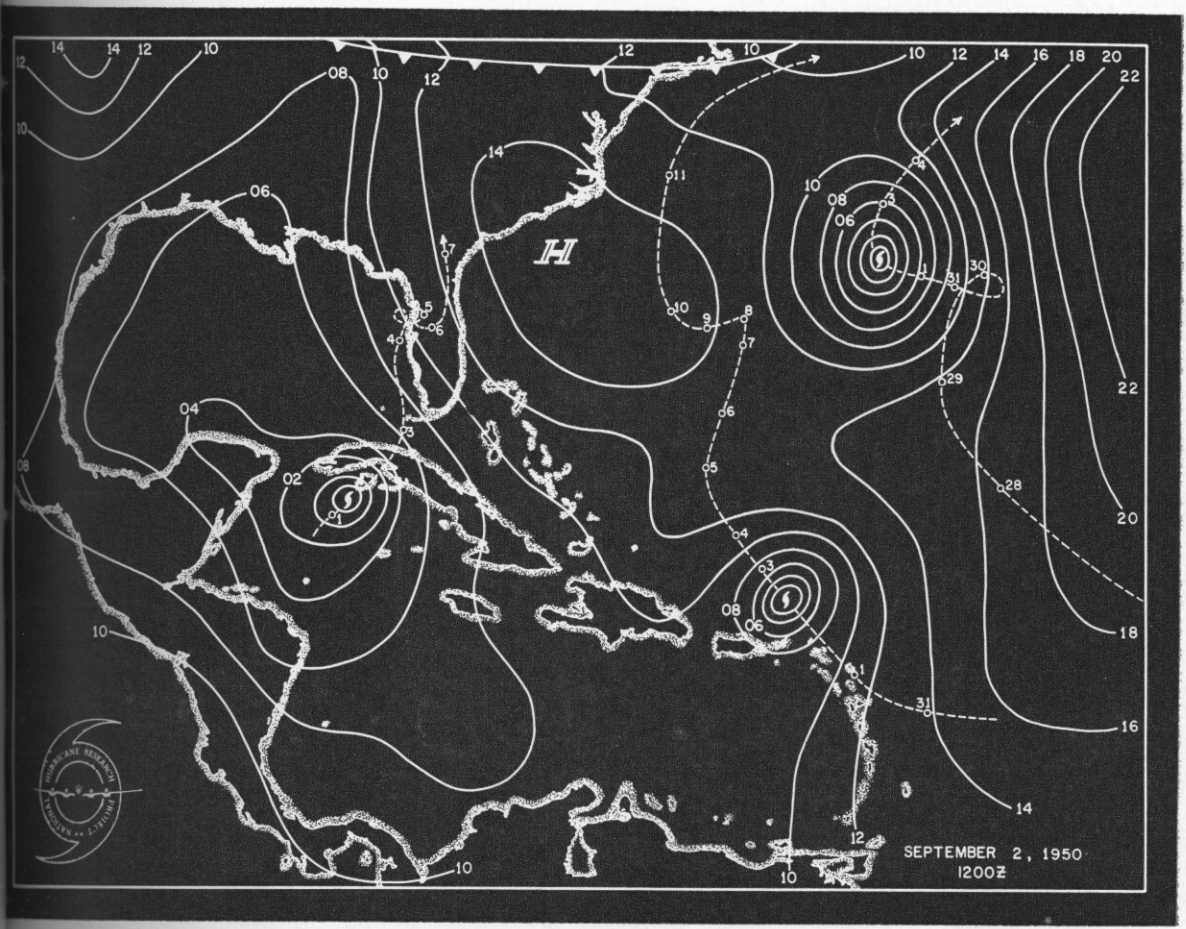

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FIG. 1. Home of the National Hurricane Center, The Aviation Building, Miami, Florida—1. 5th Floor, North Wing, Hurricane Forecast Center—DMO. 2. 5th Floor, South Wing, NHRP Headquarters. 3. Offices of Research Flight Facility. 4. 7th Floor, Joint Facilities—Library—Conference Room—Drafting—Film Reading—Radar Maintenance—Research. 5. WSR-57 Radome. 6. Navy Fleet Weather Facility. 7. Project Mercury Support Group. 8. American Airmotive Facilities at Miami International Airport where research planes are housed and maintained. 9. Weather Bureau Airport Station, Miami. All of these establishments contribute in greater or lesser degree to the National Hurricane Center.

The National Hurricane Center

HARRY F. HAWKINS, JR., *Acting Director, National Hurricane Research Project,*
LEONARD G. PARDUE, JR., *Meteorologist, District Meteorological Office,*
and CARL M. REBER, *Chief, Research Flight Facility*

IN April 1959 the National Hurricane Research Project and the newly organized Research Flight Facility moved from West Palm Beach to Miami and took up quarters adjacent to the Hurricane Forecast Center in the Aviation Building. These units comprise the National Hurricane Center designed to accelerate progress in hurricane research and to speed the application of this research to hurricane forecasting. It is the purpose of this article to describe the new complex and to discuss its objectives, capabilities, and functions as these relate to the hurricane problem.

DEVELOPMENT AND STATUS OF THE HURRICANE FORECASTING CENTER

From earliest history, residents of the Tropics have sought to predict hurricanes. Over the years, as a body of experience and tradition was acquired, many empirical rules were developed, some fairly reliable, some of occasional value, and some worthless. Concurrent with the great surge of interest in meteorology during the middle and latter parts of the nineteenth century, hurricane forecasting gradually acquired some semblance of formal standing in the more enlightened communities of the Tropics. The

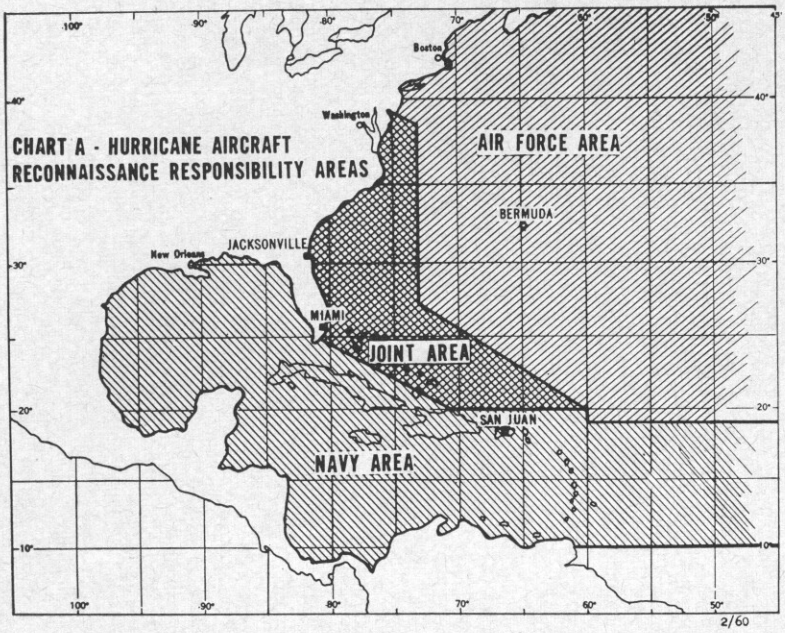

FIG. 2. Areas for which the indicated Service has prime responsibility for hurricane and tropical storm reconnaissance by aircraft.

forecasting task more often than not fell to the nearest or most interested missionary or representative of a learned institution. Marked improvement had to wait a more complete collection of synoptic information, made possible through the advance of telecommunications.

The first forecasting service, as an arm of the Federal Government, was inaugurated by the Signal Corps of the U. S. Army in 1870. Forecasting of coastal storms was an important function of the service from the beginning. The first hurricane warning of which we have definite record was issued on 23 August 1873.

Following tentative operation from locations in the Tropics, responsibility for hurricane warning, by this time a function of the civilian Weather Bureau, was centered in Washington in 1903. Earlier, during the Spanish-American War, President McKinley is said to have told Weather Bureau Chief Willis L. Moore that he feared a hurricane more than he feared enemy action.

In 1935 the Hurricane Warning Service was established with major forecasting centers in New Orleans, Jacksonville, and San Juan, in addition to Washington. The hurricane teletypewriter circuit, essential for the prompt exchange of information between coastal points, was opened that year with twelve stations strung around the coast from Jacksonville to Brownsville. Gradual growth of this circuit, particularly during the war years, increased its coverage to about fifty stations; in addition a secondary hurricane circuit was gradually built, stretching from Miami to Boston via East Coast forecast centers and vulnerable cities.

Wartime requirements led to the removal of the Jacksonville center to Miami in 1943. Here it has remained, partly because of the strategic location and partly because of the inherent value of maintaining close contact with the people to be served and the unparalleled communication and information channels available. Liaison requirements with the military led to the designation of the Miami office as the official coordinating center between Weather Bureau hurricane forecast centers in the Gulf-Caribbean-Atlantic sector on the one hand, and Air Force and Navy reconnaissance and forecast units on the other.

Radio silence imposed by wartime necessity virtually shut off information from merchant and other surface vessels in 1942. After a number of exploratory hurricane flights in 1943, aerial reconnaissance became an invaluable aid to analysis and forecasting in 1944 and subsequent years. Reconnaissance techniques and observing equipment aboard hurricane reconnaissance aircraft have been improved from year to year until this type of operation, while still regarded as a challenge

to an aircrew, is considered almost routine in nature.

Regular aircraft tracking and reconnaissance of hurricanes are carried out by Air Force and Navy units. The map (fig. 2) shows the division of areas of responsibility. When a hurricane, tropical storm, or suspicious area is known or suspected to be generating, the Service having responsibility in that area is contacted and a reconnaissance flight requested. The Navy Airborne Early Warning Squadron Four (the Hurricane Hunters) operates out of Puerto Rico while the U. S. Air Force Detachment No. 3, 55th Reconnaissance Squadron is deployed from Bermuda. Coordination of the day's flight(s), establishment of succeeding nights' and days' capabilities, agreement as to altitudes, flight tracks, and a myriad of other operational details must be decided on by the Air Force Hurricane Liaison Officer, the Commander of Navy Fleet Weather Facility, and the Weather Bureau forecaster on duty. When a shortage of trained air crews or ready aircraft develops in one or the other service, mutual cooperation prevents a situation from becoming critical.

The objectives of these flights include the location of the center ("obtain a fix") of the weather disturbance whether it be a raging hurricane or an area of squally weather, measuring the intensity of such disturbances; i.e., the strength and extent of the winds surrounding it, and the minimum pressure, heights of clouds, etc. Successive fixes at 6-hour intervals or more often are necessary for accurate tracking of the center.

The importance of these flights cannot be overestimated. One of the necessary ironies of present warning and communication facilities is that at the present time most ship captains are alert and take advantage of hurricane advisories which concern their routes. As a result, fewer ship reports are available today from the areas of hurricane activity than were available 30 years ago. In this sense at least, the issuance of effective warnings has tended to reduce the data necessary to help provide accurate warnings. Consequently, greater and greater reliance has been placed on aircraft observations.

Within the last year, however, a new battery of instruments has come into the hands of the Hurricane Forecasting Service which lessens the total reliance on aircraft as the hurricane approaches the coast. A new chain of WSR-57 radars lines the coast from Brownsville, Texas, to New England. A full-blown hurricane approaching within 200 miles of the coastline is now kept under constant radar surveillance. The WSR-57's are supplemented with reports from military establishments and by radars operated by universities. As a result, a hurricane may be under continuous surveillance of more than one radar at the same time. Equally important

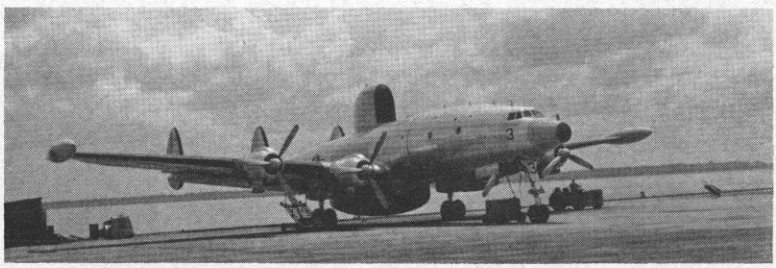

FIG. 3. The WB-3 Super Constellation built to Navy specifications and used in tropical storm and hurricane reconnaissance. The large dome below contains the APS-20E 10 centimeter weather radar, the upper dome contains a vertical scan radar which permits vertical analysis of the radar targets. These planes are characterized by extremely long range, and regularly perform 20 to 22 hour flights.

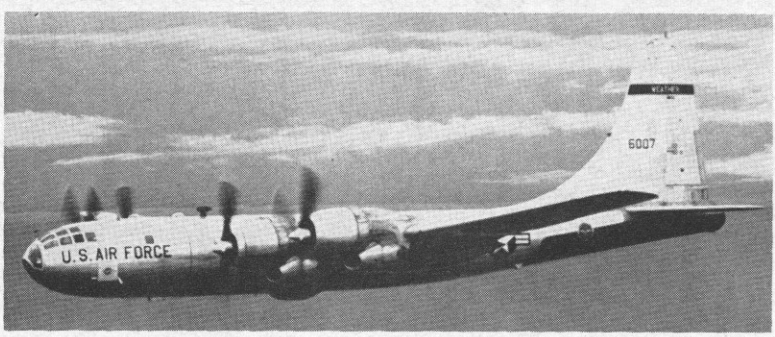

FIG. 4. The WB-50 or modified B-50 bomber of World War II used by the Air Force reconnaissance squadron based at Kindley AFB, Bermuda. These planes carry a three-centimeter radar and are equipped with accurate navigational devices which permit continuous determination of latitude and longitude plus practically instantaneous values of flight level winds.

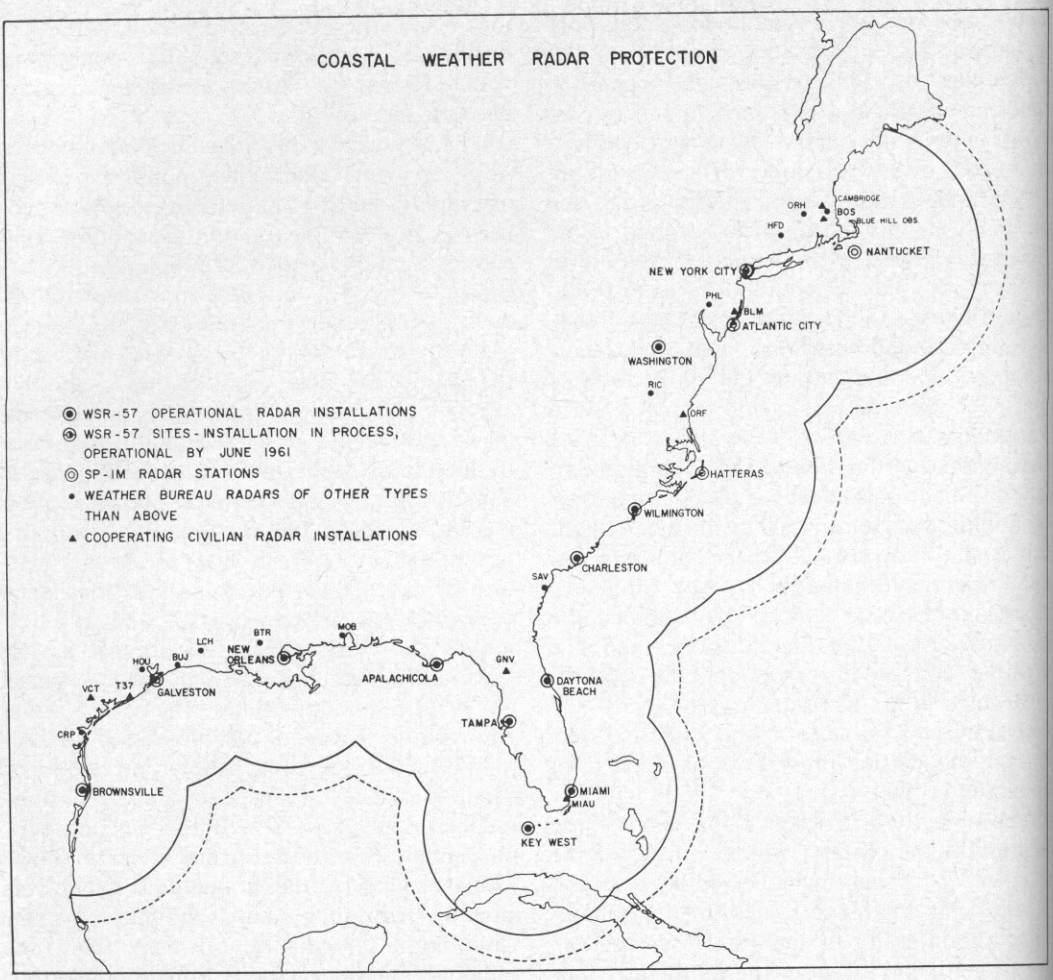

FIG. 5. The above diagram illustrates the defense net against undetected invasion by hurricane or other severe meteorological disturbance. The dashed (- - -) arcs show the extreme range of WSR-57—250 nautical miles. The solid(—) arcs show the coastal protection at ranges of 200 miles, within which any severe disturbance such as the hurricane should be clearly visible and subject to continuous tracking. The sites indicated here are augmented by Air Defense Command radars which, in hurricane emergencies, are partially manned by Bureau observers and thus supplement the protection indicated above.

is the benefit resulting from a hurricane's being tracked by a down-wind radar station as it passes out of range of an up-wind station. Reports from these radar sites are teletyped to the Hurricane Center on an hourly basis. The effectiveness of this network was more than amply demonstrated by the information and protection it afforded during Hurricane Donna of September 1960.

The drawback associated with radar coverage is the lack of quantitative information such as strength and extent of the dangerous winds and the central pressure data which cannot yet be obtained from radar observations. Research is currently underway to find out if information of this type can be obtained through radar techniques. Consequently, the reconnaissance aircraft and their radioed reports are often the only source of reliable data about very important items which tell a forecaster the size, strength, and depth of a hurricane.

In hurricane situations additional data are available from many voluntary observers who have been supplied with instruments by the Weather Bureau. The Weather Amateur Reporting Network (WARN), composed mostly of amateur radio operators, some of whom furnish their own instruments, was one of the earlier networks to secure formal recognition. Operating in Florida, it now comprises about fifty stations. Of greater geographical extent, the Cooperative Hurricane Reporting Network (CHURN) was established in 1957.

These two networks and others of local importance, plus Coast Guard, municipal, public utility, and privately operated stations, make their observations available and result in coastal observation points at twenty-five mile intervals, or less.

A Navy Fleet Weather Facility, having the primary responsibility of preparing specialized forecasts designed specifically for Naval requirements, is located adjacent to the Miami Hurricane Forecasting Center of the Weather Bureau. This proximity permits close consultation between the two groups of specialists.

The Air Force Hurricane Liaison Office coordinates the reconnaissance "plan of the day" with the detachment at Kindley Air Force Base, Bermuda. The proper Air Force authorities at Bermuda are thus kept fully advised as to the foreseeable hurricane reconnaissance requirements they may be asked to meet. They, in turn, take whatever action is possible to provide air crews and ready aircraft. In addition, the AFHLO Officer will either plan or take part in planning the flight track to be flown at altitudes requested to ensure that operational limitations of aircraft and crew are not exceeded, while at the same time the meteorological information of greatest value to the forecaster is obtained.

Further requirements on the AFHLO office are related to the hurricane forecasts and warnings. This material is tailored for Air Force use by the officer on duty and is dispatched over Air Force communication nets to the appropriate installations. Here again close touch is maintained with developing situations and the thinking behind the forecast so that interpretation and application to specific installations can be made.

Also lodged in the forecast quarters is the Project Mercury Support Group, a specialized team of forecasters and analysts supplying weather forecasts and briefings for the "man-in-space" operation at Cape Canaveral. This location was chosen because of the unequalled facilities for weather-data collection from the areas where the most frequent recoveries are expected; also, specialists with years of experience in these areas are available.

The Weather Bureau is committed to warn all civil interests in the United States and its possessions. As a facet of international cooperation, hurricane warnings are also issued for certain foreign areas. All hurricane warnings do not originate at Miami although as the National Center it is consulted by other hurricane forecast centers having specified areas of responsibility. The centers are: New Orleans, Washington, Boston, and San Juan. Continuity, guidance, and counseling are provided by Miami and the National Meteorological Center at Suitland, Maryland. Actually 75% of hurricane activity occurs within the zone of Miami's responsibility.

Being thus located quite close to so much hurricane activity and at the focal point of communication facilities entering and leaving the southeast, Miami has developed into a major forecast center and has been designated a District Meteorological Office of the Weather Bureau. One of the major problems of this office has been to obtain rapid and efficient dissemination of forecasts and warnings to the public.

It is axiomatic that no forecast or warning is useful until in the hands of those to whom it is directed. All modern means of communication are used for rapid dissemination, including national and regional teletypewriter circuits reaching all Weather Bureau offices and those of the Federal Aviation Agency. An FM radio network regularly serves seven key stations in Florida and has the capability of reaching any broadcasting station in the peninsular portion of the state. It is intended as a prototype for similar operations nationwide.

NATIONAL HURRICANE RESEARCH PROJECT

The National Hurricane Research Project was established at the behest of Congress in late 1955. Its purpose was and still remains the improvement of hurricane forecasting. This objective includes accurate prediction of the inception, intensification, and decay of hurricanes, as well as forecasts of their motions in all their eccentricities. Taken into account are such features as rapid accelerations in forward motion and rapid changes in direction. Prediction of the coastal high water levels induced by the hurricane is an integral part of this assignment.

It was recognized at the outset that sufficient observations did not exist to accomplish these aims in a physically meaningful way or, indeed, even in a satisfactory empirical

fashion. As a result, plans were made to gather new basic data on hurricanes by two means: (1) expansion of the upper-air reporting network in the West Indies into the so-called West Indies Radiosonde Network (WIRN), which now comprises some nine stations, and (2) the instrumentation of suitably stressed aircraft to probe the high-energy core of the hurricane and bring back new detailed information on the variation of meteorological parameters in the hurricane itself. These data are necessary for development of the physical picture needed to describe the mechanisms governing hurricane formation, maintenance, and motion.

In addition, plans were laid to exploit currently available climatological-synoptic data by establishing research forecast positions at the various hurricane forecasting centers. The assignments of these research people were to systematize the hurricane emergency procedures at their stations, to array synoptic data relative to hurricane situations so they could be used on future occasions and, if possible, to derive objective forecasting techniques for their particular areas of responsibility.

For the purpose of gathering the new basic investigation data, a research operations base was established in West Palm Beach, Florida, in 1956. The U. S. Air Force made available two WB-50s and one WB-47 to the Project during the 1956–58 hurricane seasons and provided air crews and facilities for their operation. The planes were heavily instrumented so that detailed meteorological observations could be recorded at a rapid rate. The functions of the Research Operations Base were to plan and stage the missions, reduce and process the data, and take part in the research work. In addition to these activities, experiments were conducted in tropical analysis and forecasting.

This basic arrangement remained in force for the three seasons 1956–1958, at the end of which time the Air Force offered to loan to the Weather Bureau the two WB-50s and the WB-47, so that if further flight activity was necessary the Weather Bureau could continue the program for an additional period with alternative arrangements for operation of the aircraft.

Investigation revealed that maintenance and operations of the WB-50s and WB-47 would be an unrealistic task for a civilian organization since these planes had heretofore been maintained exclusively by the military. In fact, studies revealed that it would be more economical to lease and operate two DC-6s than it would be to operate two WB-50s rent free. Furthermore, since the cost of operating the WB-47 was so great, the Air Force

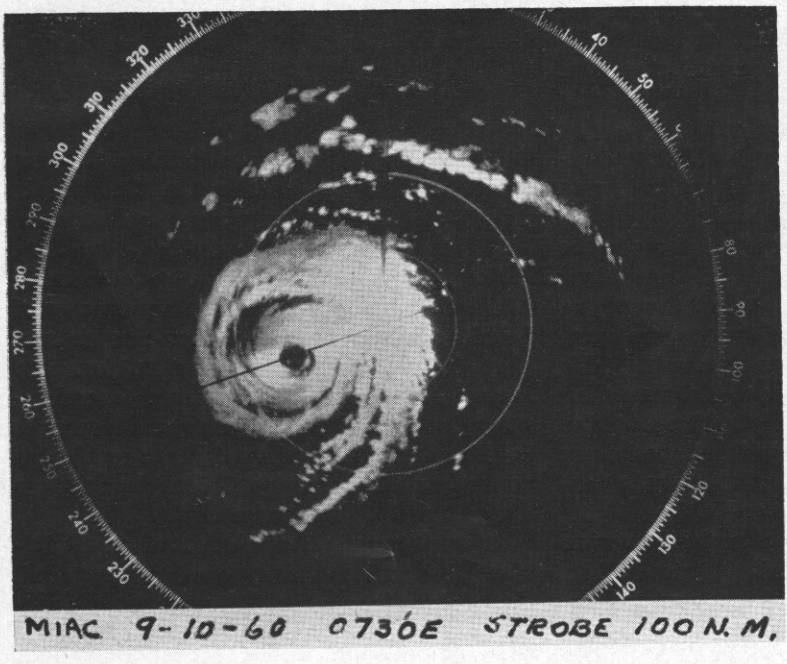

FIG. 6. A radar picture showing the complete structure of hurricane Donna taken by the WSR-57 at the National Hurricane Center on the 10th of September 1960, 0730E. The well marked circle is at a range of 100 miles from Miami (which is at the center of the scope). The well marked line of clouds from north-northwest to north-northeast of the storm (north being upper-most in the picture) is the squall line well out in advance of the hurricane proper. At about 255 degrees is the well marked eye of hurricane Donna surrounded by a solid wall of precipitation. Strong well-marked spiral bands winding into the center plus the almost solid rainshield lying between the eye and Miami make this almost a textbook picture of a model hurricane.

agreed to loan the Weather Bureau a B-57A for the necessary high-altitude reconnaissance. Following this original arrangement, the B-57 has been transferred outright to the Weather Bureau. The instrumentation of these planes was begun in 1959 and after some unforeseeable delays was completed early in 1961. Meantime, the many uses to which the planes were to be put and the unique kind of a unit which it comprises have resulted in the formation of the U. S. Weather Bureau Research Flight Facility. The capabilities and functions of this group are outlined in an adjacent section.

Concomitant with the decision to lease DC-6s, it became apparent that continued operation at West Palm Beach was impossible. Facilities for civilian maintenance of the planes were not available in that locality and a decision as to a future base of operations was required. It was at this time that the possibilities inherent in the unification of these rather diverse elements with the Hurricane Forecast Center, already long established at Miami, began to appear attractive. Consequently, in April 1959 the NHRP moved into expanded Weather Bureau quarters at the Aviation Building in Miami, thus coalescing with the Hurricane Warning Center (also the District Meteorological Office). There were obvious economical benefits to be derived by such a merger. These included the elimination of duplication in communications facilities and of communications charges between the two units which occurred when they were physically separated. Other items of similar nature included the sharing of drafting, duplication, photographic, computer, and other facilities.

More to the point, however, were the somewhat intangible advantages which might accrue in such a merging of capabilities and talents. Since the ultimate goal of the Project is improvement in prediction, it seemed highly desirable that the people working on this problem be in the closest possible touch with those currently on the "firing line" and making predictions with the techniques already at hand. This should ensure that the researcher be well aware of the most pressing problems from the forecasters' point of view while, at the same time, any step forward in research could be, after adequate testing, readily implemented in the forecast procedures.

FIG. 7. Computer installation at NHRP. An IBM 650 is used to process the raw meteorological data gathered on research flights and to reduce it to meaningful form for use by scientific investigators. The machine is also used to make mathematical computations which are too laborious to be undertaken by hand calculator.

To these joint advantages should be added a distinctly operational aspect, namely, that the Hurricane Forecast Center had at its early disposal practically all of the synoptic and other reports available in hurricane or potential hurricane situations. Thus, the complete analysis routinely performed at the station would eliminate the necessity of similar analyses being carried out at the Research Operations Base. The pooling of effort and skills in this area should result in more comprehensive and careful analyses and more thorough evaluation of the situation and its potential. This collaboration should make possible more effective deployment of the hurricane research flights and thus allow more meaningful hurricane data to be gathered. Also, in the course of such flights a certain portion of operational hurricane reconnaissance requirements can be fulfilled by the research flights themselves. Experience gathered during the 1960 hurricane season indicated that personal contact between the reconnaissance meteorologists and the forecaster on duty was extremely beneficial and informative.

It is not intended that the full scope of NHRP interests and activities be encompassed in this article. It should, however, be pointed out that in addition to the work being carried on at Miami a sizeable amount of research is pursued through research contracts, consultants, and collaborators at:

University of Chicago
Massachusetts Institute of Technology
Florida State University
University of Miami

Colorado State University
Woods Hole Oceanographic Institution
University of California at Los Angeles
New York University
University of Wisconsin
Travelers Weather Research Center
Meteorological Research Institute of Japan

At all of the above places, contributions are being made to hurricane research and the problems peculiar to meteorology in the Tropics. As results of these efforts become available, they are made known to fellow researchers and operating personnel concerned through the NHRP Preprint Series. The Preprint Series is not a formal publication but a method of rapid communication between a researcher and those concerned with his work.

Of great benefit to the National Hurricane Center and its hurricane operations are the visits these highly-specialized professionals pay to NHRP during the hurricane season, which fortunately almost coincide with academic vacations. The form which their contributions to the Center may take are varied but enlightening. A resume of last season's activities may serve as an example.

Professor N. E. LaSeur of Florida State University, and associate director of the NHRP, conducted and took part in the Center's joint map discussions, flight planning for hurricane research and reconnaissance, did research on Hurricane Cleo of 1958, and taught (together with Mr. Landers of FSU) a course in physical climatology.

Professor Herbert Riehl of Colorado State University, with Mr. Gray and Mr. Pike assisting, developed a more objective set of criteria for hurricane genesis and introduced these items into a modified map discussion. Experiments in using satellite radiation data were carried on and sea surface temperature summaries were prepared. Professor Riehl also presented his course in tropical meteorology to some 15 students.

Professor Jerome Spar of New York University spent six weeks at NHRP in a consulting capacity and contributed special low-level wind analyses to the discussions.

Messrs. Neil Frank and Edward Zipser, graduate students from Florida State University, took part in specialized map analysis for the Center and carried out research on hurricane data gathered by the research aircraft.

Among other shorter-term visitors were:

Dr. T. Fujita, University of Chicago
Dr. A. Kasahara, University of Chicago
Mr. Robert Jones University of Chicago
Mr. Keith Veigas, Travelers Weather Research Center

The many and diverse contributions these visitors have made to both operational and research problems have met with uniformly warm recognition; their cooperation ensures that maximum competence is available in any specific area where advice or assistance is needed.

THE RESEARCH FLIGHT FACILITY

As indicated in the previous section, the Research Flight Facility has only recently developed into a separate entity and was previously an integral part of NHRP. Now that planes are available on a year-round basis, they have been deployed in problems in severe storms, clear air turbulence, and the like; thus a more coherent operation is possible under the new arrangements.

Data from the research aircraft to support the hurricane research effort are obtained primarily from the specially instrumented research aircraft of the RFF. These aircraft are dispatched into areas at times best calculated to insure the collection of research data on selected meteorological conditions. Home base for the aircraft is Miami, Florida, but frequent staging operations are made from installations at Bermuda, San Juan, and other points to extend the range of operations.

The major purpose of these specially instrumented aircraft and supporting crews is the measurement of selected conditions for research purposes. Their availability and actual use in normal reconnaissance operations are limited to meeting requirements which may not always be covered readily by normal Air Force or Navy reconnaissance.

The complex measuring and data recording systems aboard each of the three aircraft—two DC-6A's and one military type B-57A—are maintained by a team of Weather Bureau technicians. These technicians also fly on the DC-6A aircraft to operate the equipment. However, since the B-57 has space for only

TABLE 1

PARAMETERS RECORDED ABOARD RESEARCH AIRCRAFT

Sub-System	Parameter	Instrument	Remarks
Meteorological parameters	Temperature	Vortex thermometer	No dynamic corrections required
	Temperature	Rosemount probe	High response rate
	Humidity	Infra-red hygrometer	
	Wind direction	Doppler radar system	
	Wind speed	Doppler radar system	
	Liquid water content	Paper-tape type	Electrical conduction principle
	Liquid water content	Hot-wire type	Electrical resistance principle
	Icing	Heated probe	On-off type instrument derives rate indirectly
	Absolute altitude	Radio altimeter	Modified Canadian Mk V.
	D-value	Hypsometer/radio altimeter	Modified Canadian Mk V.
	Absolute pressure	Pressure transducer	
	Differential pressure	Pressure transducer	To derive accurate air speed for calibration computations
Flight condition	Pitch and roll	Gyro system	
	Indicated air speed	Pitot-static system	
	True air speed	Pitot-static system plus temp. sensor.	
	Pressure altitude	Pitot-static system	
	Drift angle	Doppler system	
	Heading	N-1 compass system	
	Latitude & longitude	Doppler system	
Radar systems	Search radar	APS-20E (DC-6A only)	
	Safety radar	WP-101 on DC-6A	
	Search & safety radar	RDR-1D (B-57 only)	
Photographic system	Radar photography	O-15 cameras	
	Cloud photography	Time-lapse cameras	
	Photo-panel	Time-lapse cameras	

one crew member in addition to the pilot, a flight meteorologist flies in the aircraft to operate the equipment and direct the research data collection. Each DC-6A aircraft carries up to two flight meteorologists to perform in-flight analyses and direct the research effort. The flight meteorologists perform data review and otherwise prepare the information for scientific use when they are not flying. Crews for the aircraft are specially trained in the requirements for flying in order to obtain the most useful research data. An example of the utilization of the research aircraft may be drawn from the record on Hurricane Donna, in which almost 100 flying hours were expended in obtaining detailed measurements.

Instrumentation aboard the aircraft is aimed at obtaining the highest possible accuracy under operational conditions, and to utilize automatic data recording. A description of the total instrumentation system, divided into subsystems, is contained in Table 1.

The primary data-recording is accomplished on magnetic tape. This record, when run through a suitable computer, provides a tabulation of each parameter. Instrumental calibrations and basic computations can be accomplished at the same time the print-out is made. Data samples are usually at the rate of one complete sample each second, but rates up to one-tenth second are practicable for selected purposes. A secondary data recording of the more critical parameters is provided by photographing an instrument panel display of dial indicators.

The heart of the primary data-recording system is the digital data-handling equipment built to Weather Bureau specifications. These data-handling systems, which in some respects

FIG. 8. The eye of hurricane Cleo (1958), taken on one of the NHRP research flights. Aircraft altitude was 15,000 feet; the undercast below tops at 6,000 to 10,000 feet with the sea beneath visible through breaks. The wall cloud rises to a height of about 48,000 feet, and the eye diameter was approximately 35 nautical miles. Inside the eye, flying conditions were quite smooth but the wall cloud was as usual an area of considerable turbulence, very heavy rain, with winds over 100 miles per hour.

may be likened to digital computers, receive information from the various sensors, or other information outputs, encoded in binary form. The logic circuitry of the data-handling system is such that incoming information from each source is stored momentarily while a master sample time control system allows the information to pass through in sequence to complete the sample record. All this is accomplished in relatively few micro-seconds, following which the machine resets itself to record the next complete data sample. Master time control is provided by a crystal oscillator operating at radio frequencies which are "divided-down" to get the several different frequencies necessary to control the circuitry. This master time system also provides the real time indication by which all data recorded aboard the aircraft are identified. Built-in checks and monitor features warn the operator when the data-handling system is making mistakes and provision is made for rapid servicing in flight.

Vital to the research flying are the several radars installed on the planes. In the DC-6A aircraft, Navy-type APS-20E radars permit searching out the storm areas of interest, and the nose-installed airline type radar assists the pilots in avoiding the hard cores that present undue hazards to flight. Aboard the B-57A is a standard airline-type radar that serves both for safety of flight and, with a photographed repeater scope, records the presentations on film.

Research data from aircraft are of little, if any, practical value unless it is known where, as well as when, the information was obtained. For most flights, navigation records for research purposes are provided by a Doppler Navigation System which, with

associated circuitry, makes it possible to read out flight level wind direction and wind speed directly. The accuracy of the latitude and longitude values from these systems is often better than one per cent of total distance traveled. For selected research purposes, it is necessary to determine with the greatest possible accuracy the location of the aircraft in true coordinates and then translate this position information to virtual latitude and longitude. This adjustment relates the position of each observation to the storm system being investigated.

Cloud photography, used to study individual conditions and also to correlate occurrences, is accomplished by time-lapse cameras. On the DC-6A aircraft such photographs are taken from the nose section of the aircraft and also toward the side. On the B-57A, photography is directly ahead.

Collectively, the research aircraft now working to support the efforts of the National Hurricane Research Project probably constitute the most advanced meteorological research aircraft in general use today.

Instrumentation of the aircraft to their present state would not have been possible without the wholehearted cooperation of the Navy and Air Force who, realizing the value of this program, contributed much of the specialized equipment such as radars, navigation systems, and special probes.

Additional installations are scheduled for completion this summer, including a specially designed cross-section radar for scanning in the vertical. Also planned for installation are special vertical-motion probes which will make it possible to determine the vertical motions of the atmosphere and to measure the smaller-scale eddy circulations which are known to exist within the broadscale flow. Another installation involves the mounting of cloud seeding equipment aboard the DC-6's so that limited experiments on hurricane modification can be undertaken while the storm is too far out at sea to affect land installations.

Obviously, most of the RFF summer activities are directed solely to research purposes. Nevertheless, many operational values accrue to the National Hurricane Center through proximity to the RFF base. Communication time and difficulties do not allow for transmission of all data the flight meteorologist would like to convey to the forecaster. Debriefings after flights are very useful. In the case of the B-57, only a very limited amount

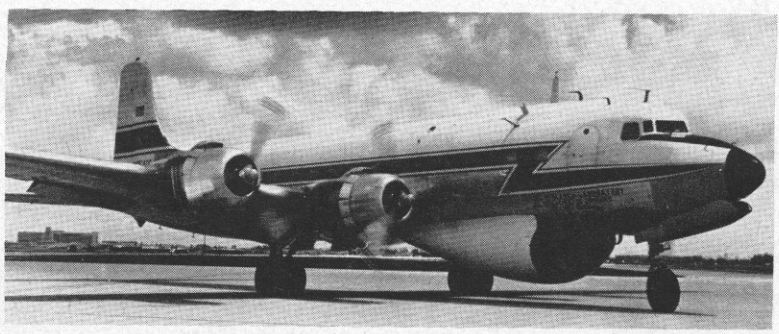

FIG. 9. One of the DC-6/A aircraft used by the Research Flight Facility in hurricane reconnaissance. The radome on the bottom contains the APS-20E weather surveillance radar as well as other antennae for Doppler Navigation and radar determination of altitude. The small dome immediately forward contains the time-lapse 16mm movie camera. Vortex and Rosemount temperature probes are immediately above window number 2 with the liquid water content meters atop the aircraft. Infrared hygrometer port is on the port side and the special pitot-static system is off the picture but on a boom extending forward from the right wing. Conventional airline radar is mounted in the nose of the aircraft.

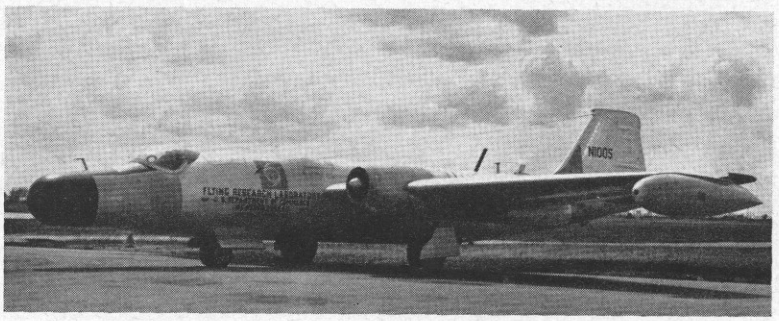

FIG. 10. The B-57/A which has been transferred by the Air Force to the Weather Bureau. This is the high altitude probe used by the Research Flight Facility, and is instrumented in an analogous fashion to the DC-6's except that the large APS-20E antennae cannot be carried on this type aircraft. Reconnaissance at altitudes of 40,000 to 45,000 feet are routine with this facility.

of data, if any, can be radioed back to base because of the many other duties of the pilot and flight meteorologist. Debriefing in this case usually includes getting the necessary observations for evaluation of meteorological conditions over the hurricane at high levels.

The researchers of NHRP must actively participate in the flight planning and also take part in the flying if meaningful data for their projects are to be forthcoming. The joint efforts of these two teams are also necessary in getting the maximum information out of any recorded set of observations. Thus proximity and cooperative effort are essential for maximum effectiveness.

SUMMARY

In the scale of such undertakings, the National Hurricane Center is still quite young, but certain advantages of the new organization can already be cited: renewed academic interest through meteorology courses given at the Center; additional material, prepared for the forecaster's consideration and presented and evaluated by skilled researchers, to be distinguished from the mere addition of another chart to an already lengthy array; material assistance to the forecast staff in critical situations through the assignment of research personnel to operational details; and benefits to research personnel from this direct exposure to operational demands.

It is reasonable to conclude that the pooling of capabilities and talents in forecasting, research, and observational technique at the Center will yield additional benefits that will be reflected in accelerated progress in hurricane research and in the improvement of hurricane forecasting.

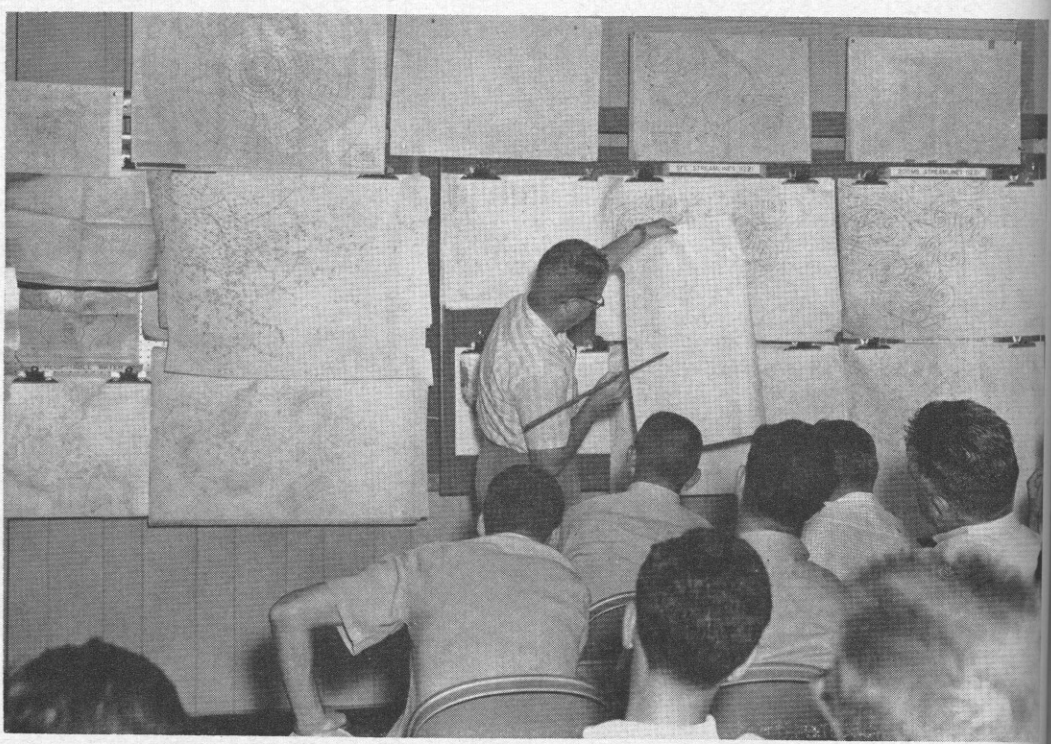

FIG. 11. Joint Map discussion at the National Hurricane Center, summer season, 1960. The various groups involved in the National Hurricane Center complex contribute specially prepared material for the joint consideration of the forecasters and research personnel in attendance.