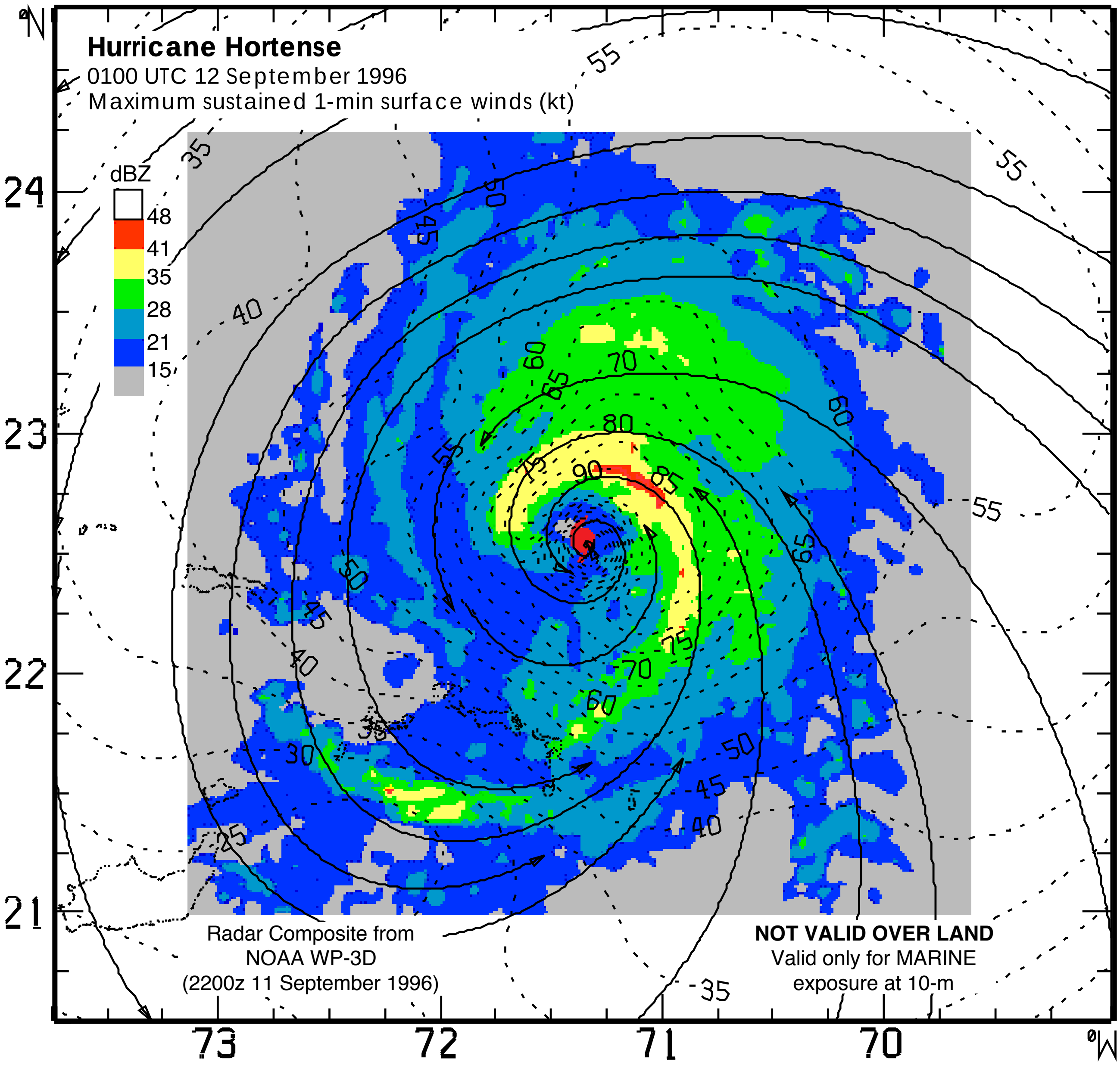
1997
Hurricane Field Program Plan



Atlantic Oceanographic and Meteorological Laboratory
Hurricane Research Division
Miami, FL

1997 Hurricane Field Program Plan

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
ATLANTIC OCEANOGRAPHIC AND METEOROLOGICAL LABORATORY
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20 JUN 97
Date

Cover: Real-time surface wind field analysis superimposed on radar reflectivities for Hurricane Hortense at 0100 UTC on 12 September 1996. The surface wind field, represented by isotachs (contour interval of 5 kt [2.5 m s^{-1}]) and streamlines, is for an ocean exposure. The radar reflectivities (dBZ) are a composite from the NOAA WP-3D lower fuselage radar for the period 2143-2214 UTC, 11 September 1996, produced in real-time onboard the aircraft and transmitted to TPC/NHC via a satellite data link. The combined wind field and radar analyses was generated in real-time by HRD scientists and sent to the hurricane specialist on duty.

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INTRODUCTION

The objective of the National Oceanic and Atmospheric Administration (NOAA) hurricane research field program is the collection of descriptive data that are required to support analytical and theoretical hurricane studies. These studies are designed to improve the understanding of the structure and behavior of hurricanes. The ultimate purpose is to develop improved methods for hurricane prediction.

Ten major experiments have been planned, primarily by principal investigators at the Hurricane Research Division (HRD)/Atlantic Oceanographic and Meteorological Laboratory (AOML) of NOAA, for the 1997 Hurricane Field Program. These experiments will be conducted with the NOAA/Aircraft Operations Center (AOC) WP-3D and Gulfstream IV-SP aircraft.

(1) Hurricane Synoptic-Flow Experiment: With the arrival of the new NOAA Gulfstream IV-SP high-altitude jet (G-IV), the Hurricane Synoptic Flow Experiment makes the transition from a research program to operations. Beginning in 1997, the G-IV will conduct routine "hurricane surveillance" missions that are essentially HRD Synoptic Flow experiments. When coordinated with these operational G-IV flights, the HRD Synoptic Flow experiment now becomes a single-option, multi-aircraft experiment. As in previous years, the experiment seeks to obtain accurate, high-density wind and thermodynamic data sets from the environment and vortex regions of hurricanes that are within 72 h of potential landfall. The availability of the G-IV, however, greatly increases the amount of environment t sampled. GPS-based dropwindsondes (GPS-sondes) deployed from the G-IV and the two NOAA/AOC WP-3D aircraft provide these data over the normally data-void oceanic regions at distances up to 810 nmi (1500 km) from the hurricane center. Mandatory and significant level GPS-sonde data, transmitted in real time, are used to prepare official forecasts at the Tropical Prediction Center/National Hurricane Center (TPC/NHC). These data are also incorporated into objective statistical and dynamical hurricane prediction models at TPC/NHC and the National Centers for Environmental Prediction (NCEP). In a research mode, these data help improve short and medium term (24-72 h) hurricane track predictions, study the influence of synoptic-scale fields on vortex track and intensity, and assess methods for obtaining satellite soundings.

(2) Extended Cyclone Dynamics Experiment: This is a multi-option, multi-aircraft experiment which uses in–situ and radar data from both WP-3Ds flying at 500 mb and the G-IV flying at 200 mb to monitor the structure and evolution of a hurricane on a spatial scales ranging from the convective and mesoscale in the vortex core (10-100 nmi [18-185 km] radius) to the synoptic-scale (1,000 nmi [1,850 km] radius) in the surrounding large-scale environment over a nominal period of 48 h. The WP-3D and G-IV data will be augmented by flight–level data from Air Force WC-130s flying reconnaissance at 700 mb within 110 nmi (200 km) of the center The experiment goal is a better understanding of how lateral interactions between the vortex and the synoptic–scale environment control hurricane intensity and motion.

(3) Vortex Motion and Evolution Experiment: This multi-option, dual-aircraft experiment is designed to observe the structure and evolution of the inner core wind field of developing or mature hurricanes. True dual-Doppler data are obtained within 45 nmi (75 km) of the center with a horizontal grid spacing of 0.5 nmi (1 km). Three such data sets over 7 h, 2.3 h apart, are obtained during the mission, along with 9 pseudo-dual-Doppler data sets, to examine the evolution of the inner vortex. These data are supplemented by five rings of 6 or more GPS-sondes, from 50-160 nmi (95-300 km). This dropwindsonde coverage will provide azimuthal wave number 0 and 1 outside the inner core of the vortex, thus specifying the overall strength of the vortex and its three-dimensional "steering" asymmetry. Satellite information from NCEP and the University of Wisconsin will supplement the sonde coverage above flight level.

(4) Tropical Cyclogenesis Experiment: This multi-option, multi-aircraft experiment is designed to study one of the most important unanswered questions in tropical meteorology is: How does a tropical disturbance become a tropical depression with a closed surface circulation? This experiment seeks to answer the question through multilevel aircraft penetrations using dropsondes, flight-level data, and radar observations on the synoptic, meso, and convective spatial scales. It will focus particularly on both thermodynamic transformations in the mid-troposphere and lateral interactions between the disturbance and its synoptic-scale environment.

(5) Tropical Cyclone Wind Fields Near Landfall: This multi-option, single-aircraft experiment is designed to study the changes in tropical cyclones (TC) near surface wind structure near and after landfall. An accurate description of the TC surface wind field near and after landfall in real-time is important for warning, preparedness, and recovery efforts. HRD is developing a real-time surface wind analysis system to aid the TPC/NHC in the preparation of warnings and advisories in TCs. The analyses could reduce uncertainties in the size of hurricane warning areas. Flight-level and Doppler wind data collected by a NOAA WP-3D will be transmitted to TPC/NHC where they could result in improved real-time and post-storm analyses. Doppler data collected near a WSR-88D would yield a time series of three-dimensional wind analyses showing the evolution of the inner core of TCs near and after landfall.

(6) Tropical Cyclone Air-Sea Interaction Experiment: This multi-option, dual-aircraft experiment is designed to determine the contribution of pre-existing and storm-induced ocean features to changes in tropical cyclone intensity and surface wind field structure. This experiment seeks to address this issue through single-level aircraft penetrations using GPS dropsondes, flight-level data, air-deployed drifting buoys, AXBTs, AXCPs, C-band scatterometers(C-SCAT)/profiler, stepped frequency microwave radiometer (SFMR) and airborne Doppler radar observations on the synoptic, meso, and convective scales. It will focus particularly on both thermodynamic and wind field transformations in the boundary and lateral interactions between the tropical cyclone and its synoptic-scale environment.

(7) Rainband Structure Experiment: This multi-option experiment can be flown by either dual aircraft or a single aircraft. This experiment will lead to a better understanding of the structure of hurricane rainbands and should provide valuable insight on the possible influence of rainbands on the overall intensity of a storm. It is designed to investigate the kinematic and thermodynamic structure of hurricane rainbands and the environment in which they are embedded. Many previous studies have explored the nature of hurricane eyewalls, yet few have actively examined the three-dimensional wind field and thermodynamics associated with rainbands. Doppler radar and flight level data will be gathered inside and outside of rainbands, including those that may form a convective ring around the eyewall, and GPS sondes will be utilized to gain mid-tropospheric and boundary layer information. There are two formal options included in this experiment. The first is designed to study 'principal' rainbands, and the second will be used to investigate concentric eyewalls. A rainband module (lasting 30-60 min) that can be flown with other experiments is also included.

(8) Electrification of Tropical Cyclone Convection Experiment: This is a multi-option, single-aircraft experiment designed to seek out the electrically active convection in TCs for in-depth study. The first option uses the recently installed Desert Research Institute (DRI) electric field mills and the DRI induction ring to obtain both the electric field strength and the charge carried on the hydrometeors within the hurricane eyewall and convective rainbands. The information will help to determine why some hurricane convection is electrically active while other, similar, hurricane convection is not. A second option will investigate the relationship between cloud physics, vertical velocity, and the occurrence and location of cloud-to-ground (CG) lightning within ~325 nmi (600 km) range of the NLDN. Together, these data sources and techniques should lead to a better understanding of the characteristics of the convective processes that lead to lightning in hurricanes and, possibly, to intensity changes of the storms.

(9) Eyewall Vertical Motion Structure Experiment: This single-option, dual-aircraft experiment is designed to map the three-dimensional spatial structure of the hurricane eyewall up- and downdrafts and to use dual-Doppler analysis to relate the vertical motion structure to the effects of environmental shear through the eyewall. It utilizes both NOAA WP-3D aircraft flying highly coordinated flight patterns to map the three-dimensional structure of eyewall vertical motions. The target storm must have an eyewall (or a developing one) with significant areas of deep convection.

(10) Clouds and Climate: This single-option, single-aircraft experiment uses the airborne Doppler radar and microphysics instrumentation to accumulate a data base of cloud precipitation properties over a wide range of environments. This study emphasizes the exploitation of airborne in-situ and remote sensing (radar), together with satellite observations of clouds. It will provide a data base for studies of clouds and precipitation mechanisms, their effect on climate, and provide ground truth for satellite techniques.

CONCEPT OF OPERATIONS

1. Location

The primary base of operations will be Miami, Florida, with provision for deployments to Bermuda, Barbados, Jamaica, Puerto Rico, and St. Croix for storms in the Atlantic basin (including the Atlantic Ocean and the Caribbean Sea).

Deployments may be implemented to U.S. coastal locations in the western Gulf of Mexico for suitable Gulf storms and to western Mexico for eastern Pacific storms. Occasionally, post mission recovery may be accomplished elsewhere.

2. Field Program Duration

The hurricane field research program will be conducted from 15 July through 31 October 1997.

3. Research Mission Operations

The decision and notification process used for hurricane research missions is illustrated, in flow chart form, by Fig. A-1 (Appendix A). The names of those persons who are to receive primary notification at each decision/notification point shown in Fig. A-1 are in Tables A-1 and A-2 (Appendix A). In addition, contacts are maintained each weekday among the directors of HRD/AOML, TPC/NHC, and AOC to discuss the "storm outlook."

Research operations must consider that the research aircraft are required to be placed in the National Hurricane Operations "Plan of the Day" (POD) 24 h before a mission. Once operational "fix" requirements are accepted, the research aircraft must follow the operational constraints described in section 7.

4. Task Force Configuration

Two NOAA/AOC WP-3D aircraft (N42RF and N43RF), equipped as shown in Tables B-1 and B-2 (Appendix B), will be available for research operations throughout the 1997 Hurricane Field Program (on or about 15 July through 31 October). When possible, the G-IV jet aircraft will be used with the WP-3Ds during the Synoptic-Flow Experiment.

5. Field Operations

5.1 Scientific Leadership Responsibilities

The implementation of HRD's 1997 Hurricane Field Program Plan is the responsibility of the field program director, who is, in turn, responsible to the HRD director. The field program director will be assisted by the field program ground team manager. In the event of deployment, the field program ground team manager shall be prepared to assume overall responsibility for essential ground support logistics, site communications, and HRD site personnel who are not actively engaged in flight. Designated lead project scientists are responsible to the field program director or designated assistants. While in flight, lead project scientists are in charge of the scientific aspects of the mission being flown.

5.2 Aircraft Scientific Crews

Tables C-2.1 through C-2.10 (Appendix C) list the scientific crew members needed to conduct the 1997 hurricane field experiments. Actual named assignments may be adjusted on a case-by-case basis. Operations in 1997 will include completion of detailed records by each scientific member while on the aircraft.

5.3 Principal Duties of the Scientific Personnel

A list of primary duties for each scientific personnel position is listed at the end of the plan (after Appendix C).

5.4 HRD Communications

The HRD/Miami Ground Operations Center (MGOC) will operate from offices at AOML on Virginia Key (4301 Rickenbacker Causeway, Miami, Florida) or from TPC/NHC (11691 S.W. 17th Street, Miami, Florida). TRDIS operations will also be conducted at TPC/NHC.

During actual operations, the senior team leader of the MGOC, or his designee, can be reached by commercial telephone at (305) 229-4407 (HRD/TPC/NHC) or at (305) 361-4400 (HRD/AOML). At other times, an updated, automated telephone answering machine [(305) 361-4534 (at AOML)/(305) 229-4408 (at TPC/NHC)] will be available at the MGOC. Also, MGOC team leaders and the field program director can be contacted by calling their respective telepager phone number (available at a later date).

MGOC, operating from AOML or TPC/NHC, will serve as "communications central" for information and will provide interface with AOC, TPC/NHC, and CARCAH (Chief, Aerial Reconnaissance Coordinator, All Hurricanes). In the event of a deployment of aircraft and personnel for operations outside Miami, HRD's field program ground team manager will provide up-to-date crew and storm status and schedules through the field program director or the named experiment lead project scientist. HRD personnel who have completed a flight will provide information to MGOC, as required.

6. Data Management

All requests for data gathered during the 1997 Hurricane Field Program should be forwarded to: Director, Hurricane Research Division/AOML, 4301 Rickenbacker Causeway, Miami, Florida 33149.

7. Operational Constraints

Hurricane research missions are routinely coordinated with hurricane reconnaissance operations. As each research mission is entered into the planned operation, a block of time is reserved for that mission and operational reconnaissance requirements are assigned. A mission, once assigned, must be flown in the time period allotted and the tasked operational fixes met. Flight departure times are critical. Scientific equipment or personnel not properly prepared for flight at the designated pre-take-off or "show" time will remain inoperative or be left behind to insure meeting scheduled operational fix requirements.

8. Calibration of Aircraft Systems

Calibration of aircraft systems is described in Appendix C (en-route calibration). True airspeed (TAS) calibrations are required for each flight, both to and from station and should be performed as early and as late into each flight as possible (Fig. C-1).

EXPERIMENTS

9. Hurricane Synoptic-Flow Experiment

Program Significance: Hurricane Synoptic Flow experiments conducted prior to 1997 used the WP-3Ds and the previous Omega-based generation of dropwindsondes (ODWs) to gather vertical profiles of wind, temperature, and humidity within 540 nmi (1,000 km) of hurricanes. The experiment was typically conducted over the data-sparse oceanic regions of the western Atlantic or Gulf of Mexico roughly 48-72 hours before the projected landfall of a mature hurricane on the coast of the United States. While satellites typically provide wind data in the upper and lower troposphere (near 200 and 850 mb, respectively), the middle levels - the levels most directly related to TC motion - are frequently almost void of observations. As a result, operational models often fail to predict important changes of storm speed or direction due to inadequate initial data, rather than inadequate physics of the prediction models. During the Synoptic Flow experiments, dropwindsondes released from the WP-3Ds defined the hurricane's surrounding large-scale flow, particularly in the critical 400-700 mb middle tropospheric layer.

Synoptic Flow experiments were conducted on 18 occasions from 1982-93. Recent research at HRD, NCEP, and GFDL with this sample of cases demonstrates conclusively that the dropwindsonde data produce significant improvements in the operational models that are the primary guidance for TPC/NHC's official track forecasts. For consensus (averaged) forecasts from the three primary operational dynamical models (HRD's barotropic VICBAR model, GFDL's nested grid model, and NCEP's global spectral model), the dropwindsondes were responsible for statistically significant 12-60 hour track forecast improvements of 16%-30%. These improvements are at least as large as the accumulated improvement in operational forecasts achieved over the last 20-25 years.

The size of these improvements suggests that operational GPS-sonde missions will be a highly effective way to reduce the costs associated with overwarning. Hurricane warnings are usually issued 18-24 hours before landfall for a length of coastline averaging 300 nmi (555 km). The swath of damaging winds and tides caused by hurricanes that strike land, however, is generally <100 nmi (185 km). Thus, current forecasting skill results in an overwarning zone of ~200 nmi (370 km) that is a trade-off between maximizing warning lead time and keeping the warning area as small as possible. In 1992, TPC/NHC estimated that the preparation costs alone incurred by the public placed under a hurricane warning exceed \$346,000 km^{-1} of coastline. By comparison, the cost of a three-aircraft dropwindsonde mission using 70 GPS-sondes (at \$600 apiece) and 27 hours of flight time (at \$2,800 per hour) is about \$128,000. If forecasters are able to reduce the over-warning area by only 5% (20 km (12 nmi)) by taking advantage of GPS-sonde-improved numerical guidance, the cost of obtaining the data will be well worth the expenditure.

In addition to direct operational benefits of the Synoptic Flow experiments, diagnostic case studies of the dropwindsonde observations have led to improvements in our basic understanding of hurricane motion. Analyses of the existing data sets have helped to document the relationship between vortex motion and the environmental flow and have provided the first observational evidence of the beta-gyres commonly found in barotropic models. A multi-scale, nested analysis of the Gloria data set has also been completed. This analysis identified a "steering envelope" in the deep-layer-mean flow just outside Gloria's eyewall. The Gloria analyses have also been used to document, for the first time, the potential vorticity (PV) distribution in a hurricane's core and environment.

Current work involving the inversion of Gloria's PV distribution is expected to provide a powerful new tool for diagnosing the synoptic features responsible for a given hurricane's steering flow. Preliminary results indicate that upper level PV features may dominate, and may act from large distances from the hurricane's center. Synoptic Flow experiments using the G-IV and WP-3Ds simultaneously will offer an unprecedented opportunity to document these features.

Objectives: The ultimate objective of these experiments is the improvement of short- and medium-range (24-72 h) hurricane track prediction. The immediate requirement is the collection of one or two data sets of GPS-sonde wind and thermodynamic soundings within 810 nmi (1500 km) of hurricanes that are threatening the United States. These data will be used by TPC/NHC and NCEP to prepare real-time analyses and official forecasts and will be incorporated in the objective statistical and dynamical hurricane prediction models.

Dropwindsondes have been shown to be capable of improving hurricane track forecasts; however, the optimal deployment strategy is unknown. The increased range and altitude capability of a three-aircraft coordinated pattern, coupled with the PV inversion tools currently being developed, will allow the determination of optimal deployment strategies. Other research, which is just under way, is the initialization of multi-level models with the dropwindsonde data. With their added complexity, the current sample of cases is probably not large enough to adequately study the behavior of these models. These data sets will also be used to study the influence of synoptic-scale fields on changes in vortex intensity and track and to assess satellite-derived products.

Mission Description: To collect a relatively uniform distribution of GPS-sonde soundings within ~810 nmi (1500 km) of hurricanes over a minimum period of time, both NOAA/AOC WP-3D aircraft will operate simultaneously in regions within and surrounding the hurricane. The WP-3Ds will operate simultaneously and in coordination with operational surveillance missions of the G-IV. Specific flight tracks will vary depending on such factors as the location of the storm, relative both to potential bases of operation and to particular environmental meteorological features of interest, and the operational pattern being flown by the G-IV.

A sample mission is shown in Fig. 1. The two WP-3D aircraft and the G-IV will begin their missions at the same time. Subject to safety and operational constraints, each WP-3D will climb to the 500-mb level (about FL 180) or above, then proceed, step-climbing, along the routes assigned during preflight. It is particularly important that both aircraft climb to and maintain the highest possible altitude as early into the mission as aircraft performance and circumstances allow, and attain additional altitude whenever possible during the mission.

GPS-sondes are released in one of two modes. Beyond 40 nmi (75 km) from the storm center, drops are made at pre-assigned locations, generally every 25 min or 120 nmi (222 km). These drop locations are provided with the particular mission flight tracks 2 h before blockout. Within 40 nmi (75 km) of the hurricane's center, drop locations are specified relative to the center's position (e.g., 40 nmi (75 km) north of the eye). During in-storm portions of the mission, drops will be made with possible spacing < 8 min or 40 nmi (75 km). Efforts should be made to avoid making drops in heavy precipitation, unless necessary. Aircraft turns are not expected to affect the GPS-sonde wind accuracy, but we expect to continue the practice of making drops AFTER THE TURN IS COMPLETE.

Usually, one aircraft will fly through the hurricane center and execute a Doppler figure-4 pattern. This aircraft's Doppler radar should be set to scan perpendicular to the aircraft track. "Hard" center fixes are not desirable. On the downwind leg of the figure-4, the Doppler should be set to record forward and aft (F/AST) continuously. If both aircraft penetrate the storm, the figure-4 pattern will generally be executed by the second aircraft through the storm, and the first aircraft through will collect vertical incidence Doppler data. Coordination with potential USAF reconnaissance is necessary to ensure adequate aircraft separation. The in-storm portion of the missions is shown schematically in Fig. 2, although the actual orientation of these tracks may be rotated.

Of paramount importance is the transmission of the GPS-sonde data to NCEP and TPC/NHC for timely incorporation into operational analyses, models, forecasts, and warnings. Operational constraints dictate an 0600 or 1800 UTC blockout time, so that the GPS-sonde data will be included in the 1200 or 0000 UTC analysis cycle. Further, limiting the total block time to 9 h allows adequate preparation time for aircraft and crews to repeat the mission at 24-h intervals. These considerations will ensure a fixed, daily real-time data collection sequence that is synchronized with NCEP and TPC/NHC's analysis and forecasting schedules.

HURRICANE SYNOPTIC FLOW EXPERIMENT

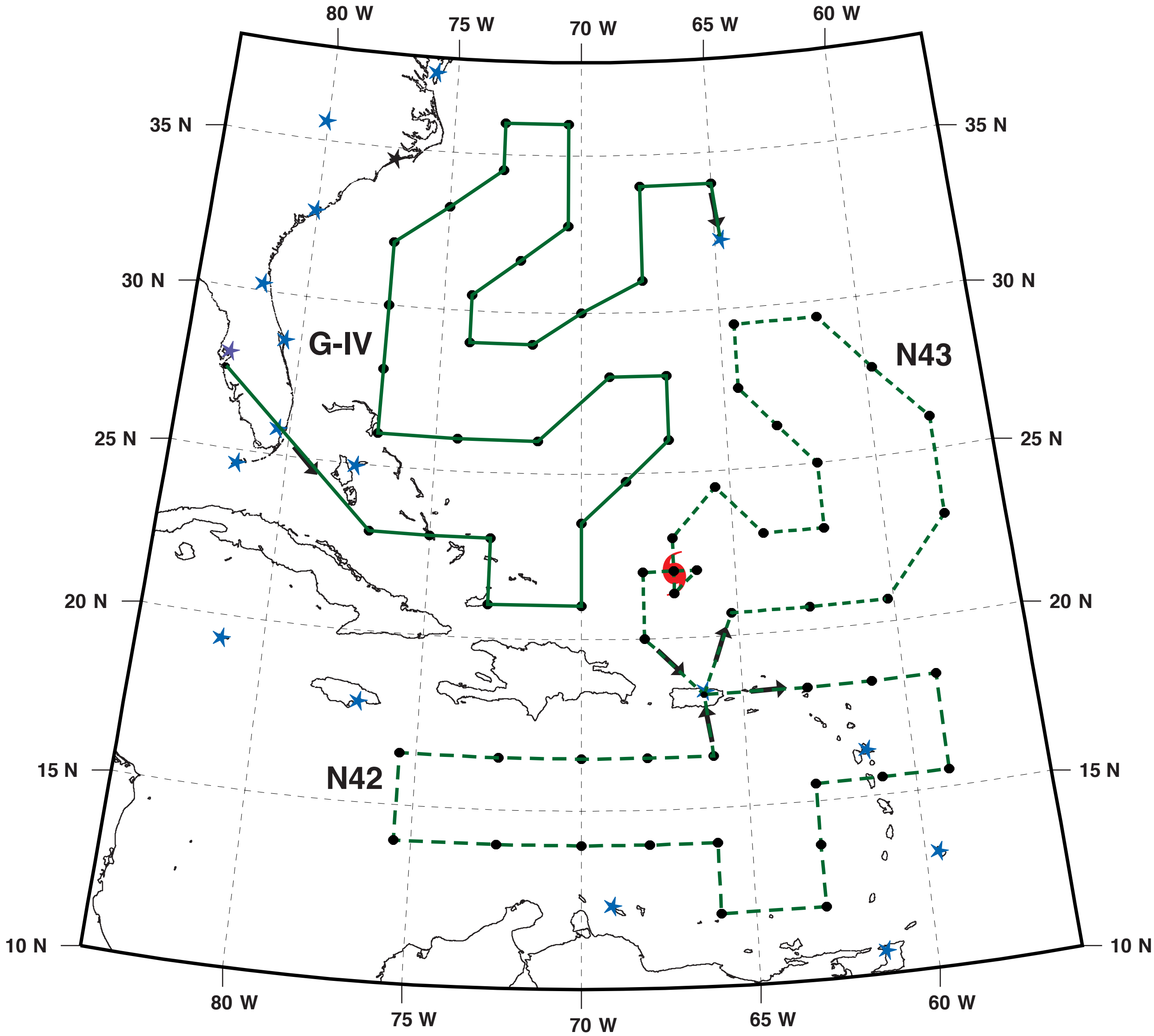


Fig. 1 Sample Environmental Pattern

HURRICANE SYNOPTIC FLOW EXPERIMENT

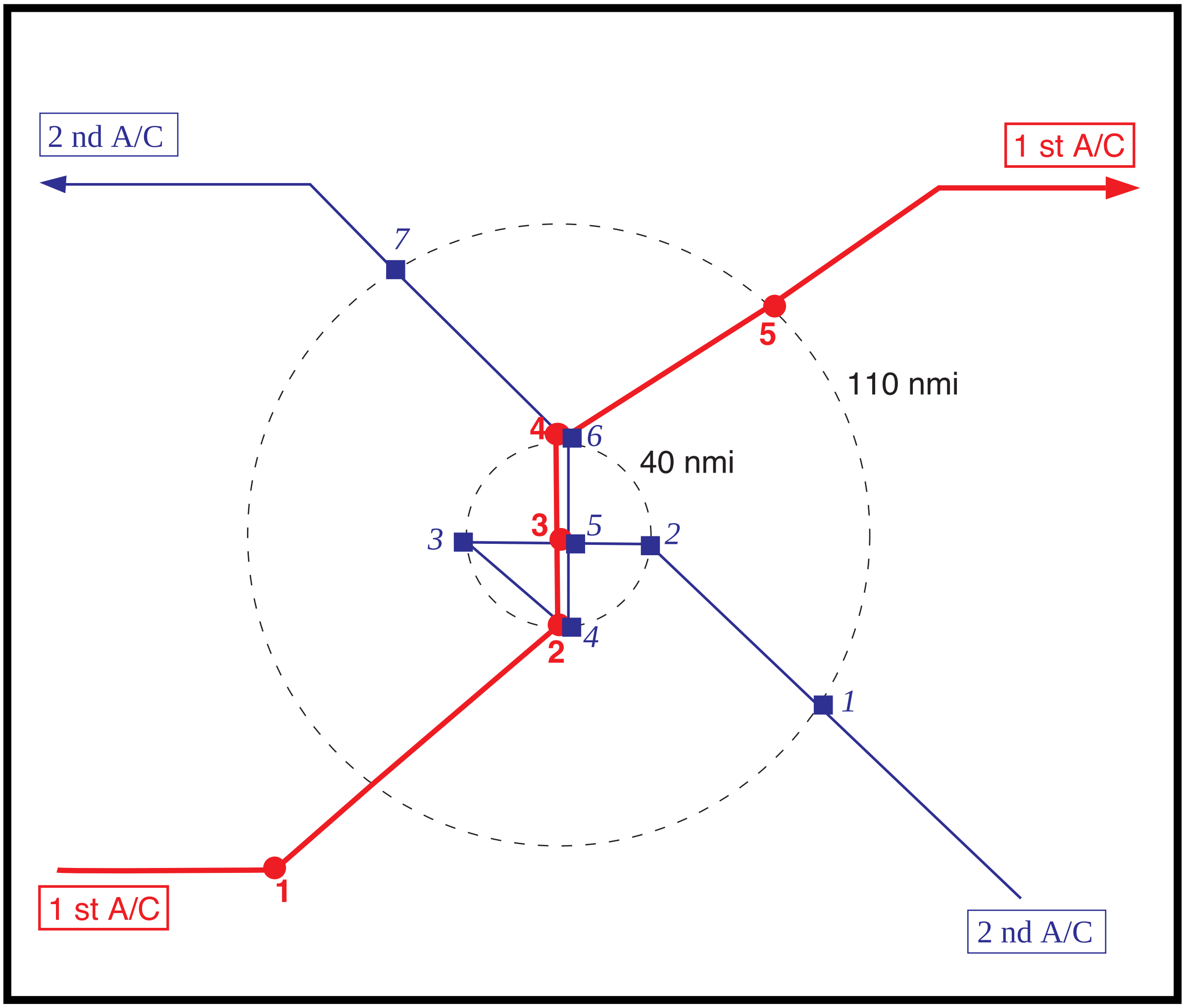


Fig. 2 In-Storm Patterns

• Note 1.	Within the 40 nmi (75 km) range ring, all legs are on cardinal tracks.
• Note 2.	The second aircraft through the storm will execute the Doppler "figure-4" pattern. The Doppler radar should be set to continuously scan perpendicular to the track during radial penetrations and to F/AST on the downwind leg.
• Note 3.	Numbered symbols (◆, ■) reflect scheduled drops for each aircraft.
• Note 4.	Drop #5 in the "figure-4" pattern occurs on the second pass through the eye.
• Note 5.	A/C 1 should collect vertical incidence Doppler data during storm penetration.
• Note 6.	If missions are not repeated, then block times may exceed 9 h. In addition to the GPS-sonde data, 3-4 RECCO's h^{-1} should be transmitted during each mission.

Special Notes: Missions similar to the Synoptic Flow missions may be flown in non-hurricane conditions to collect GPS-sonde data sets for satellite sounding evaluations. These missions differ from the normal experiment as follows:

- Block times are 10 h, and the experiment is not repeated on the following day.
- In-storm portion of the pattern (Fig. 2) is omitted and no Doppler data are collected.
- The G-IV does not participate in the mission

10. Extended Cyclone Dynamics Experiment (XCDX)

Program significance: Starting in the early 1980s, the Vortex Dynamics Experiment was the focus of observational studies of the evolution of the hurricane's inner core. It accumulated an archive of more than 1500 radial passes in 30 different Atlantic and Eastern Pacific hurricanes. The main scientific result was formulation of an observationally based model in which hurricane intensity and structure change were explained in terms of convective rings, circles of convection coincident with maxima of the swirling wind that intensify and propagate inward. Remaining unanswered questions were the dynamics of the rings' formation and factors that control timing and amount of intensity changes driven by their evolution.

Since 1991, HRD has received the flight–level observations from routine reconnaissance flights by the IWRS-equipped WC-130Hs of the 53rd Weather Squadron. Although these observations have proven to be of excellent quality, their value is compromised by a lack of vertical velocity, microphysics, or radar reflectivity data. The USAF aircraft typically remain on station for 4–6 h, flying figure-four (ALFA) patterns at 850 or 700 mb (5,000 or 10,000 ft (1.5 or 3.0 km) altitude) with 150 nmi (278 km) legs oriented along the cardinal directions. Between sorties, there is usually a gap of 6–7 h during which no aircraft is in the hurricane, except near landfall when the interval between fixes decreases to 3 h. Experience with USAF observations from the 1991 through 1996 seasons shows that they document the evolution of the hurricane core well, but that they are even more valuable when augmented by occasional sorties of the NOAA WP-3Ds. The advent of the G-IV and introduction of GPS–based dropsondes present a long–awaited opportunity to study vortex interaction with vertical shear of the environmental wind and with upper tropospheric waves that are hypothesized to control hurricane intensification through eddy influxes of angular momentum.

The conventional reason offered for shear's negative effect on intensification has been that it ventilates the vortex by blowing warm air out of the core aloft to raise the hydrostatic surface pressure. Recent theoretical work suggests that the asymmetric stability and distribution of convection associated with shear–induced tilt of the vortex may be more significant. The net result of eddy momentum import is not a direct spin up of the swirling wind but outflow near the tropopause, which destabilizes the tropospheric column and strengthens the convection. Rapid intensification, apparently triggered by this mechanism, is a one of the most challenging problems that forecasters face. We think that we know how the eddies that start the process work. Jet airplanes and the new dropsondes are ideal tools to go looking for them.

Objective: This experiment is designed to study the mechanisms by which environmental shear and eddy fluxes control hurricane intensity changes. A secondary objective is to obtain a time series of eye soundings to study the thermodynamics of intensity change. It will use some aircraft to monitor the evolution of the vortex core and others to observe the environmental flow over a large domain. It has two options, vortex and synoptic.

Mission Description: The Vortex Option uses Air Force flight-level data to monitor the vortex core and frequent dropsondes and Radar data from the WP-3Ds or G-IV to monitor interactions with the environment. If only the WP-3Ds are available, they fly successive star patterns out to 200–300 km at 600–500 mb {15,000-18,000 ft [5-6 km)}. If jet aircraft are available, they will fly at or near their ceiling dispensing dropsondes through nearly the whole tropospheric column, either in a pattern similar to the P–3s or in a circumnavigation. Thus, the combined flights can observe both the near–field environmental forcing and the vortex response.

The synoptic option emphasizes the sampling of the large-scale environment while placing less of a priority on obtaining data in the vortex core. This option uses the flight–level, radar reflectivity, and Doppler data, along with dropsondes from the WP-3Ds to map the synoptic-scale environment surrounding the vortex. At the same time the flight–level data and dropsondes from the G–IV combined with Air Force flight–level data will be used to monitor the temporal changes of the axisymmetric vortex over a period of up to 48 h to study the eddies that mediate the synoptic–scale forcing.

Vortex option: This option uses the USAF WC-130s to observe the evolution of the hurricane core while the WP-3Ds fly long radial legs above them to collect radar data and observe the interaction with the synoptic-scale environment, and the G-IV circumnavigates the storm or flies a crossing pattern in the upper troposphere dispensing dropsondes. The ideal target is a northward moving hurricane that has a fairly small Central Dense Overcast (CDO) and is expected to interact with vertical shear, an approaching mid-latitude trough, or a upper-level low.

The WP-3Ds will fly at 500–600 mb isobaric level {15,000-18,000 ft [5-6 km)} in a pattern of three equilateral triangles with common vertices at the hurricane's center (Fig. 3). Altitude will be the highest attainable that avoids too much aircraft icing and electrical charging. It is crucial to the analysis that a fixed pressure altitude is maintained throughout. The nominal leg length will be 250-300 nmi (460-550 km), but the size of the pattern will be adjusted to make the legs as long as possible given the available aircraft range. The WP-3D will deploy dropwindsondes in a symmetrical pattern to map the vertical structure of the secondary circulation below flight level. On each passage through the center it will deploy a pair of sondes as close to the axis of vortex rotation as possible to study the thermodynamic transformations of the eye. The basic XCDX is three maximum-endurance sorties in 42 h or four in 56 h, with alternating aircraft and crews. Nominal flight duration will be 10 h with 4 h gaps between flights. The second aircraft will take off 14 h after the first. The third sortie, the second flight by the first aircraft, will depart 14 h after the second sortie or 18 h after the first sortie landed. Thus, take-off times by the same aircraft and crew will shift 4 h later in the next day on subsequent flights. The aircraft may, depending upon altitude, spend a third or a quarter of its time in icing conditions under the CDO, which may compromise range. A variation of the XCDX is one or more sorties at the same altitude with shorter legs and more frequent drops in the eye to focus on eye thermodynamics.

The G–IV, if available, will fly a hexagonal circumnavigation of the storm at 600 nmi (1,110 km) radius, dispensing up to five dropsondes on each of the six sides of the pattern (Fig. 4). The aircraft will dispense dropsondes frequently along track. Since the purpose of the pattern will be to observe asymmetric structure and compute eddy correlations, the turn points will need to move with the hurricane, placing a premium on accurate navigation.

Synoptic Option: Data will be collected within ~540 nmi (1,000 km) radius of the vortex center over approximately a ~48 h period when an unsheared or well organized tropical storm or hurricane is interacting with an upper-level trough or cold low. Since in this option the goal is to document the structural changes of an intensifying vortex, it is desirable that the system be moving along an upper-level trough, since this minimizes the chance that the system will experience extensive shearing. Successful completion of this option requires that the G-IV, if available, fly a cloverleaf type pattern with legs of ~240 nmi (450 km) at maximum altitude (41,000 ft [~200 mb]) dispensing GPS-sondes along the way (Fig. 5). The two WP-3D aircraft would fly a synoptic-flow type pattern at 21,000 ft (~400 mb) dispensing GPS-sondes between ~320-540 nmi (600-1,000 km) radius to document the large-scale structure outside the region sampled by the G-IV aircraft (Fig. 6). One of the two WP-3D aircraft would fly through the center and collect Doppler and reflectivity data.

XCDX EXPERIMENT

Vortex Option

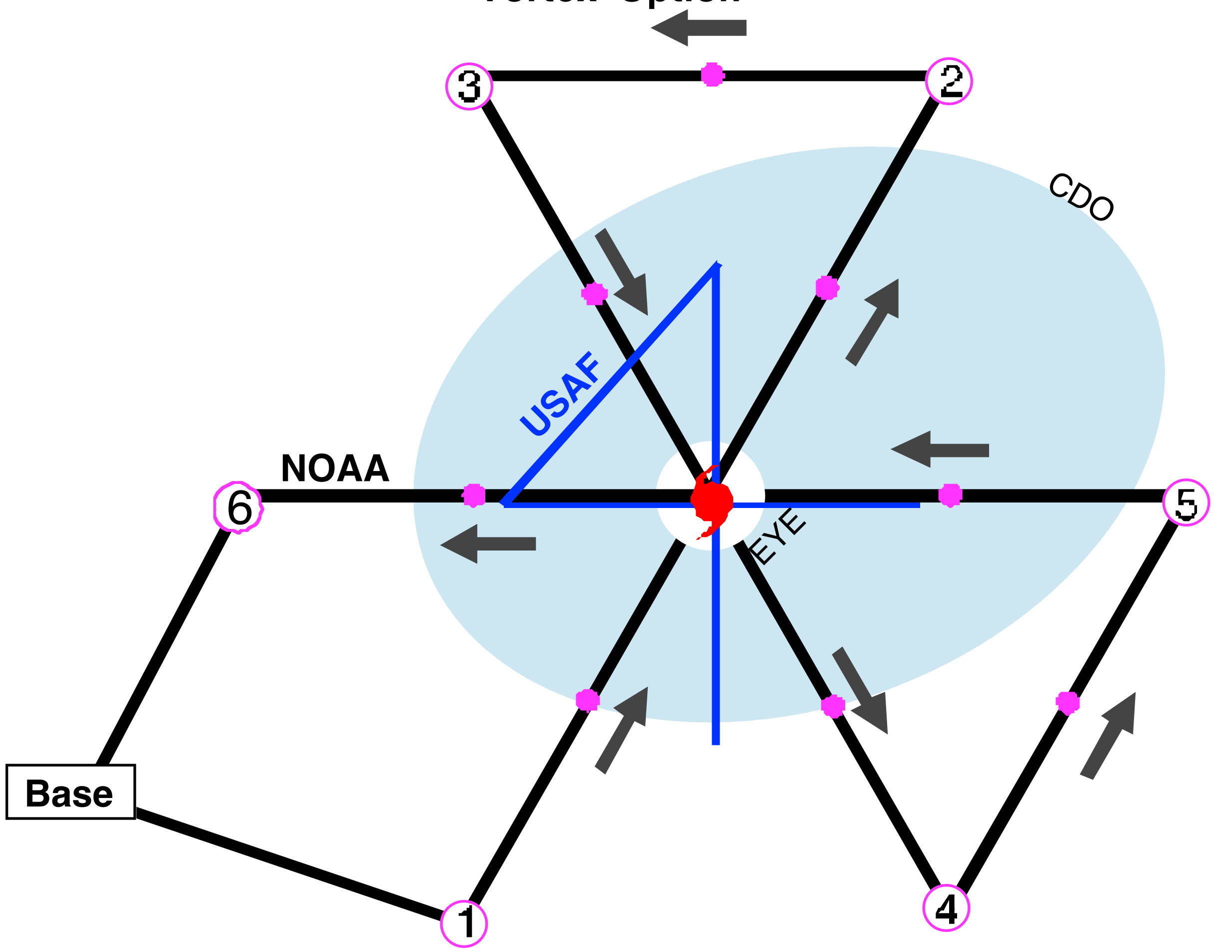


Fig. 3. WP-3D pattern

• Note 1.	WP-3Ds fly **1–§–2–3–§–4–5–§–6** at 500 mb pressure altitude if the CDO is small, or at 15,000 ft (4.5 km) radar altitude to avoid icing if it is large. The leg length is the longest possible given aircraft range and ferry distance to the storm.
• Note 2.	Dropsonde observations occur at the midpoints of the legs, after turns, and in pairs as close to the axis of rotation as possible on each passage through the eye.
• Note 3.	Each WP-3D sortie will take off is 19 h after the previous one.
• Note 4.	Airborne Doppler radar scans perpendicular to the aircraft track within 50 nmi (95 km) of the center on penetration and exit, and on F/AST elsewhere.

XCDX EXPERIMENT

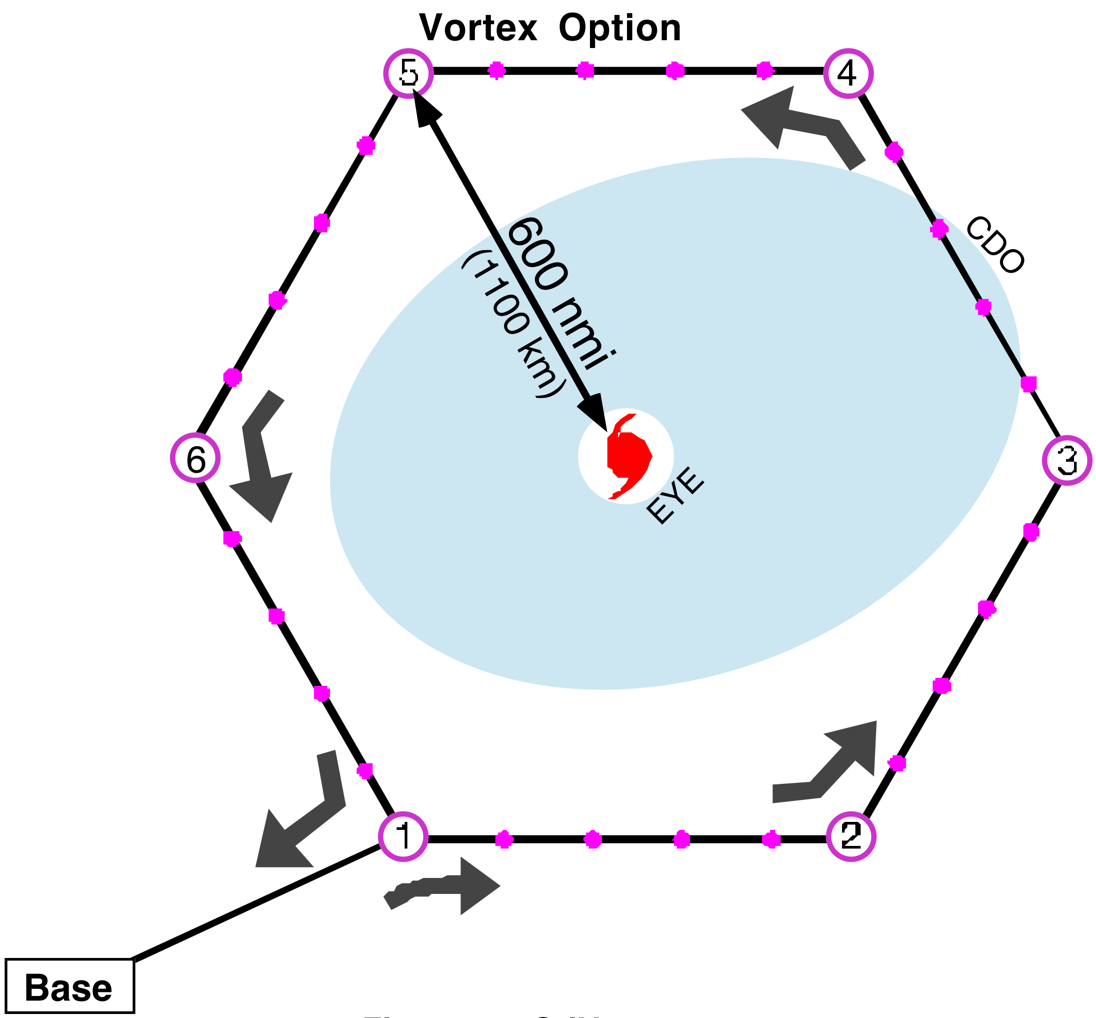


Fig. 4. G-IV pattern

• Note 1.	The G–IV flies 1–2–3–4–5–6. The entire pattern is at 200 mb pressure altitude with turn points positioned relative to the moving hurricane center point. Leg length (pattern radius) will be adjusted to use the available range.
• Note 2.	Four or five GPS-sondes will be deployed on each leg.

XCDX EXPERIMENT

Synoptic Option

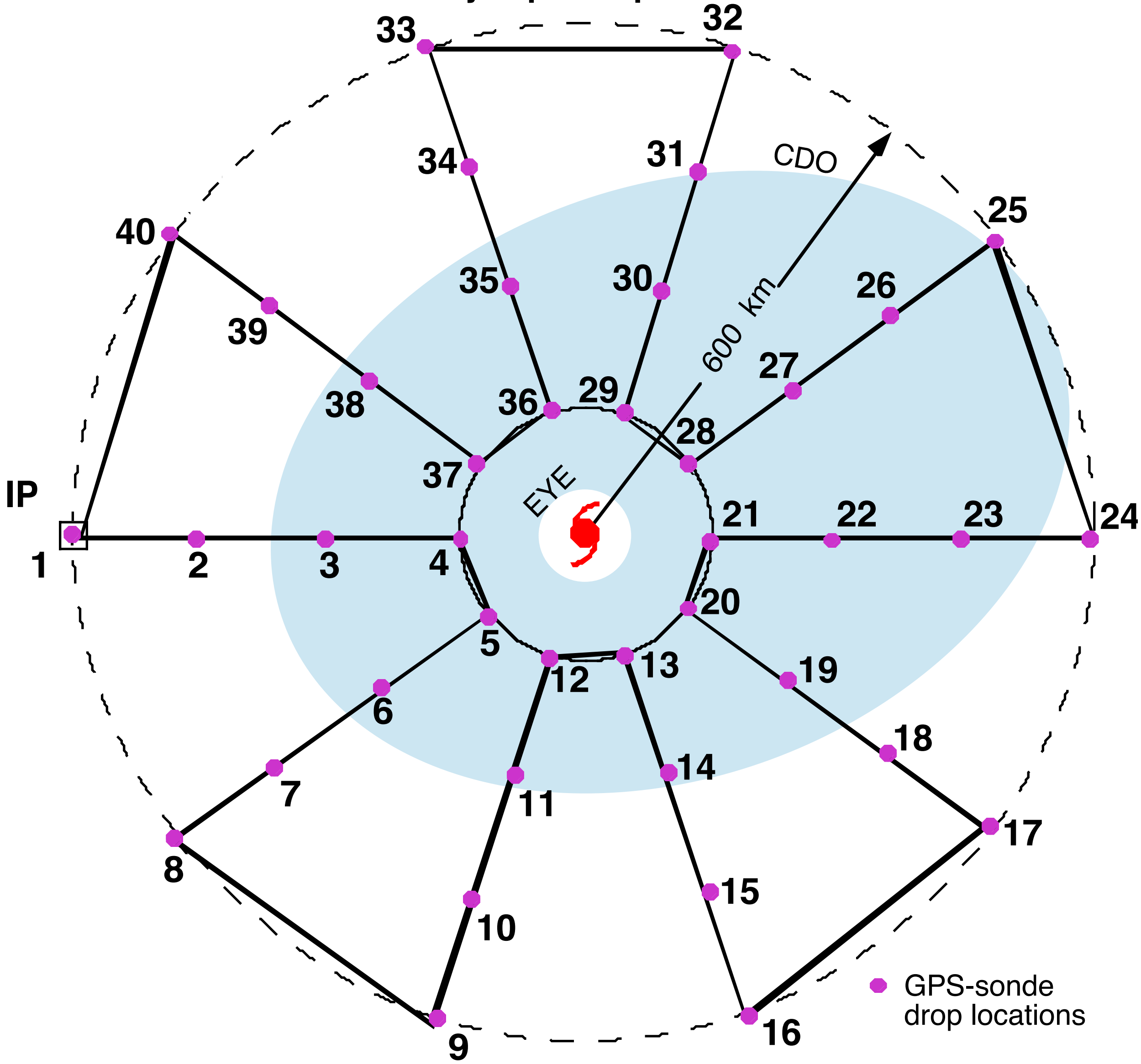


Fig. 5. G-IV pattern

• Note 1.	The pattern may be entered along any compass heading.
• Note 2.	During the ferry to the IP, aircraft will climb to the 41,000 ft (200 mb) or above. All legs are 240 nmi (450 km) in length. Leg lengths can be adjusted to account for convection extended outside the 80 nmi (150 km) radius along one or more of the legs.

XCDX EXPERIMENT

Synoptic Option

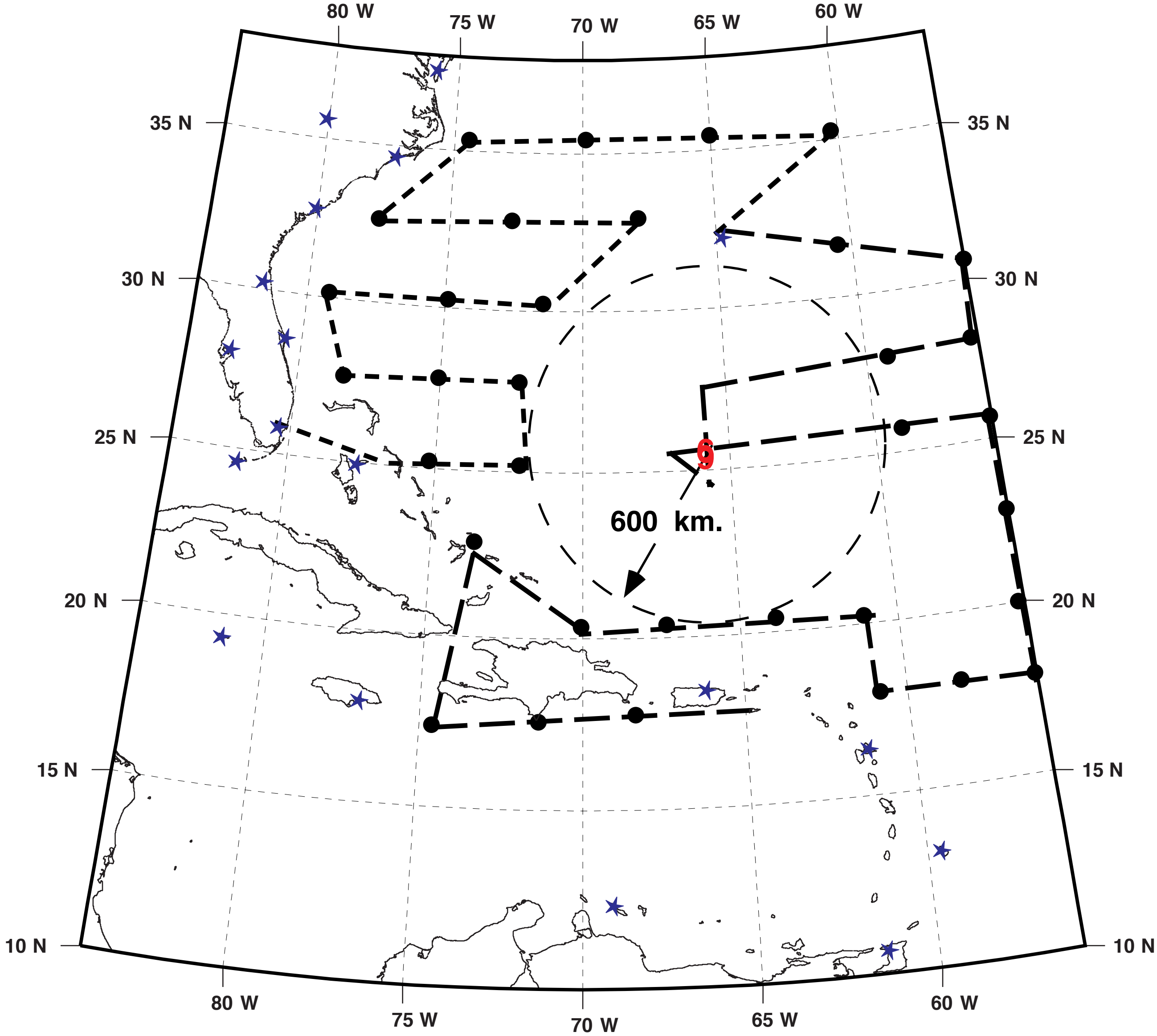


Fig. 6. WP-3D pattern

• Note 1.	● denotes scheduled drops for each aircraft. All drops should be beyond 600 km radius.
• Note 2.	One aircraft will execute the Doppler "figure-4" pattern. The Doppler radar should be set to continuously scan perpendicular to the track during radial penetrations and to F/AST on the downwind leg. The "figure-4" aircraft should collect vertical incidence Doppler data during storm penetration.
• Note 3.	Within the "figure-4" pattern all legs are 40 nmi (75 km) and along cardinal tracks.

11. Vortex Motion and Evolution (VME) Experiment

Program Significance: Recent research suggests that important environmental controls on TC motion are active in the region surrounding the cyclone's inner core, within about 160 nmi (300 km) of the center. Studies of Hurricane Gloria from Doppler radar and Omega dropwindsonde (ODW) data suggest that the environmental influence on vortex motion was maximized in an envelope near 35 nmi (65 km) radius from the center. The region from 35-160 nmi (65-300 km) has been poorly sampled during other experiments, which have either emphasized the vortex core or more distant environment. A primary goal of the VME experiment is to improve our understanding of how the environmental "steering" flow is communicated to the vortex.

Analyses of the core regions of TCs based on the pseudo-dual-Doppler approach have increased our understanding of TC structure and evolution. However, recent studies using true dual-Doppler data collected from simultaneous passes by two aircraft through the center of hurricanes, have shown that significant changes in storm intensity and structure can take place over periods of 30 min or less. This implies that the pseudo-dual-Doppler analyses obtained from a single aircraft's "figure-4" pattern may be subject to significant aliasing. Additional true dual-Doppler data sets are required to properly document the evolution of the vortex core region over periods of several hours.

In 1995, two successful VME experiments were conducted in Hurricanes Iris and Luis, using the previous (Omega) generation of dropwindsonde. In 1997, new instrumentation and techniques will substantially improve the capabilities of the WP-3Ds and motivate the collection of additional data sets. With the new GPS-sondes it will be possible to double the horizontal sounding resolution in the radial direction to 25 nmi (46 km). In the inner core, improvements over dual-Doppler data sets can be obtained by altering the antenna scanning mode to yield triple-Doppler wind fields.

Objectives: The immediate goal of the experiment is to document the three-dimensional wind field within 160 nmi (300 km) of hurricanes. Data sets obtained from the experiment will be used to relate asymmetries in the wind field to short and long-term vortex motion. The data sets will also be used to determine the utility of the pseudo- and true-dual-Doppler approach, and in further studies of the role of inner core asymmetries in hurricane motion, structure, and evolution.

Doppler radar and GPS-sondes will be used to document the 3-dimensional wind field within 160 nmi (300 km) of hurricanes. True dual-Doppler data are obtained within 45 nmi (83 km) of the center with a horizontal grid spacing of 0.6 nmi (1 km). Three such data sets over 7 hours, 2.3 hours apart, are obtained during the mission, along with 9 pseudo-dual-Doppler data sets, to examine the evolution of the inner vortex. These data are supplemented by five rings of 6 or more GPS-sondes, at 50, 75, 100, 130, and 160 nmi (93, 139,185, 241, and 300 km). This GPS-sonde coverage will provide azimuthal wave numbers 0 and 1 at these radii, to specify the overall strength of the vortex and its basic "steering" asymmetry. Satellite information from NCEP and University of Wisconsin will supplement the GPS-sonde coverage above flight level.

Mission Description: The experiment involves both WP-3D aircraft flying simultaneous, pre-determined and coordinated patterns. One aircraft will fly at maximum altitude and release dropwindsondes; the second aircraft will fly at a lower, fixed altitude. Both aircraft will collect Doppler radar data. The upper aircraft will also collect cloud physics and atmospheric electric field data on an opportunity basis for use by other investigators. The experiment requires a strong tropical storm or hurricane, with unsheared convection near the center to provide Doppler targets. The length of the flight patterns requires that the cyclone be within about 540 nmi (1,000 km) of the base of operations, and it must be far enough from land to allow drops 160 nmi (300 km) from the center. The experiment requires only one day of flying, but may be repeated on subsequent days if desired.

Subject to safety and operational constraints, takeoff time will be 1800 UTC, to coordinate with the NCEP analysis cycle at 0000 UTC. The flight pattern for the dropwindsonde (upper) aircraft is shown in Fig. 7. During the ferry to the initial position (IP), the aircraft will climb to the 500-mb level (about FL 180) or above. The 400 mb level (about FL 250) should be reached as soon as possible and maintained throughout the pattern, unless icing conditions dictate a lower level for safety. GPS-sondes will be released at the indicated locations in Fig. 7, and pseudo-dual Doppler data will be taken during the three "figure-4" portions of the pattern. If there is active convection in the outer triangle portions of the pattern, Doppler data should be taken there as well. All drop and turn points in the pattern are relative to the moving center of the storm. Mandatory and significant level information from selected GPS-sondes will be transmitted in real time back to NCEP and TPC/NHC.

The flight pattern for the lower aircraft is given in Fig. 8. Subject to safety and operational constraints, the lower aircraft should take off first. Flight level for the lower aircraft will be FL 100. The lower aircraft will drop no GPS-sondes. In order to ensure that true-dual-Doppler data are obtained, communication and coordination between the two aircraft are essential. Both aircraft must begin their patterns at their respective IP's simultaneously. Once the patterns are underway, all coordination maneuvers should be performed by the lower aircraft; except for changes in air-speed, the upper aircraft will fly its pattern as drawn. In addition to the IP's, the start of each inbound Doppler leg should be coordinated.

VME Coordination Points	
Upper Aircraft Nav Point	**Lower Aircraft Nav Point**
1 (IP)	1 (IP)
2	2
4	4
8	10
10	12
14	18
16	20

The lower aircraft is responsible for delaying to ensure that the CP's are reached simultaneously by both aircraft. The patterns are designed so that the lower aircraft will reach the CP's shortly before the upper aircraft; however, if necessary, the lower aircraft may cut the corners at points 9 and 17 in order to reach points 10 and 18 on time.

The lower aircraft at times may fly an optional "circle" pattern just outside the eyewall. This would occur just after the coordinated figure-4 pattern (i.e., immediately following nav points 5, 13, or 21 [Fig. 8]). The aircraft flies a nearly circular pattern (actually numerous short straight-line segments) just outside the eyewall while the tail radar scans in a fore/aft sequence. The circle must be as small as possible, since no data are obtained from the inner 40% (by radius) of the circle. The lower aircraft would re-coordinate with the upper aircraft at nav point 10 or nav point 18 (Fig. 8).

Special Note: The VME pattern can be coordinated with the Hurricane Surveillance Mission flown by the G-IV. The VME pattern is unchanged while the G-IV drops sondes in the hurricane's large-scale environment.

VORTEX MOTION AND EVOLUTION EXPERIMENT

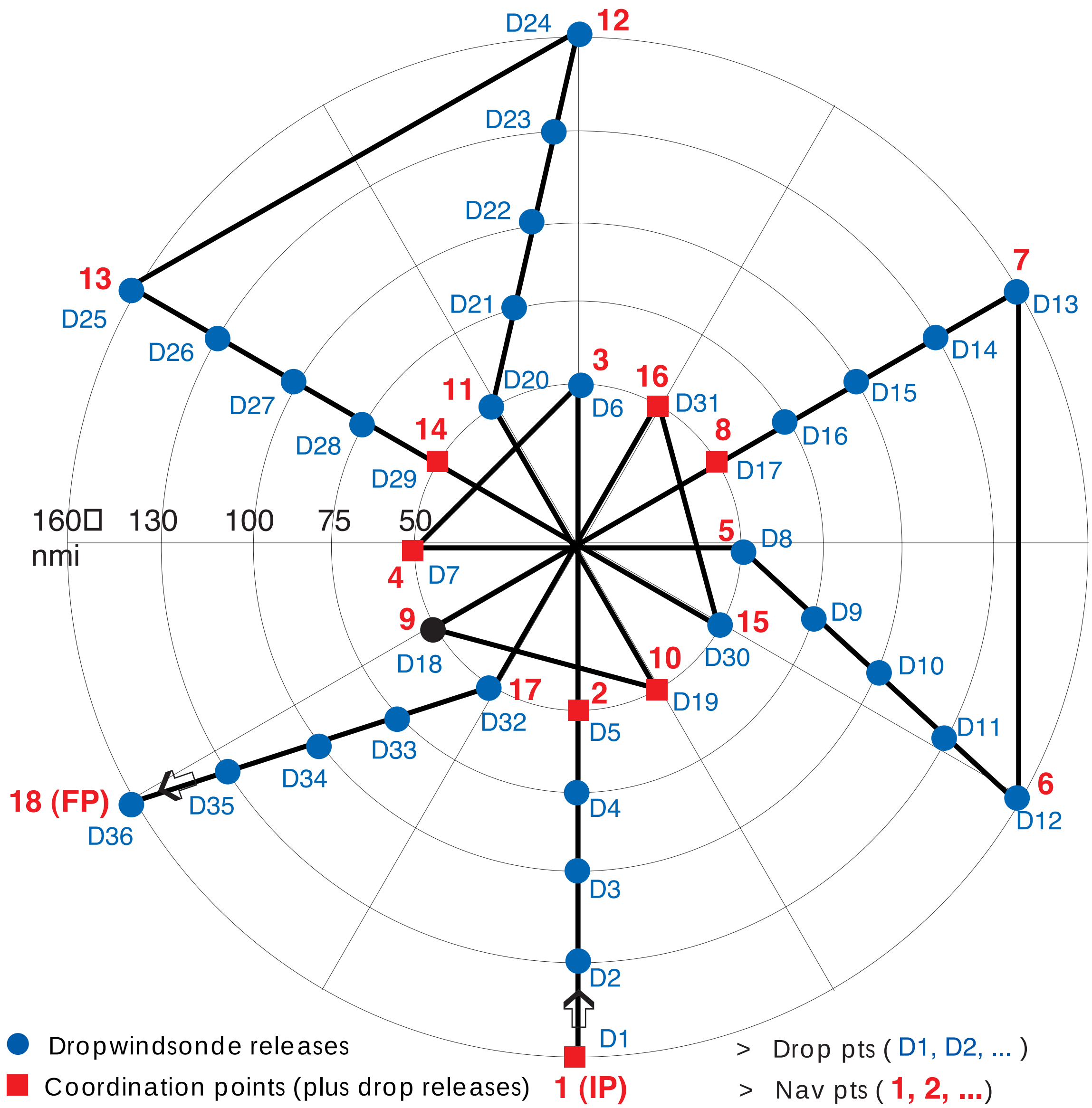


Fig. 7. Upper Aircraft Flight Pattern

- Note 1. True airspeed calibration is required.
- Note 2. During the ferry to the **IP**, aircraft will climb to the 500 mb level (about FL 180). The 400 mb level (about FL 250) should be reached as soon as possible and maintained throughout the remainder of the pattern, unless icing or electrical conditions require a lower altitude.
- Note 3. The pattern may be entered along any compass heading. The **IP** and coordinating points (**CP**) must be reached simultaneously with the lower aircraft. The lower aircraft is responsible for ensuring that these points are reached simultaneously.
- Note 4. There are **no** scheduled drops in the eye. It may be desirable to make a drop during the second pass of each figure-4, assuming clearance from the lower aircraft and USAF reconnaissance aircraft. GPS-sonde frequencies should be coordinated with USAF aircraft. All drops are to be made after turns.
- Note 5. Airborne Doppler radar scans continuously perpendicular to the track on radial penetrations at radii<50 nmi (95 km) , and F/AST during the rest of the pattern.
- Note 6. Aircraft should not deviate from the pattern to find the wind center in the eye.

VORTEX MOTION AND EVOLUTION EXPERIMENT

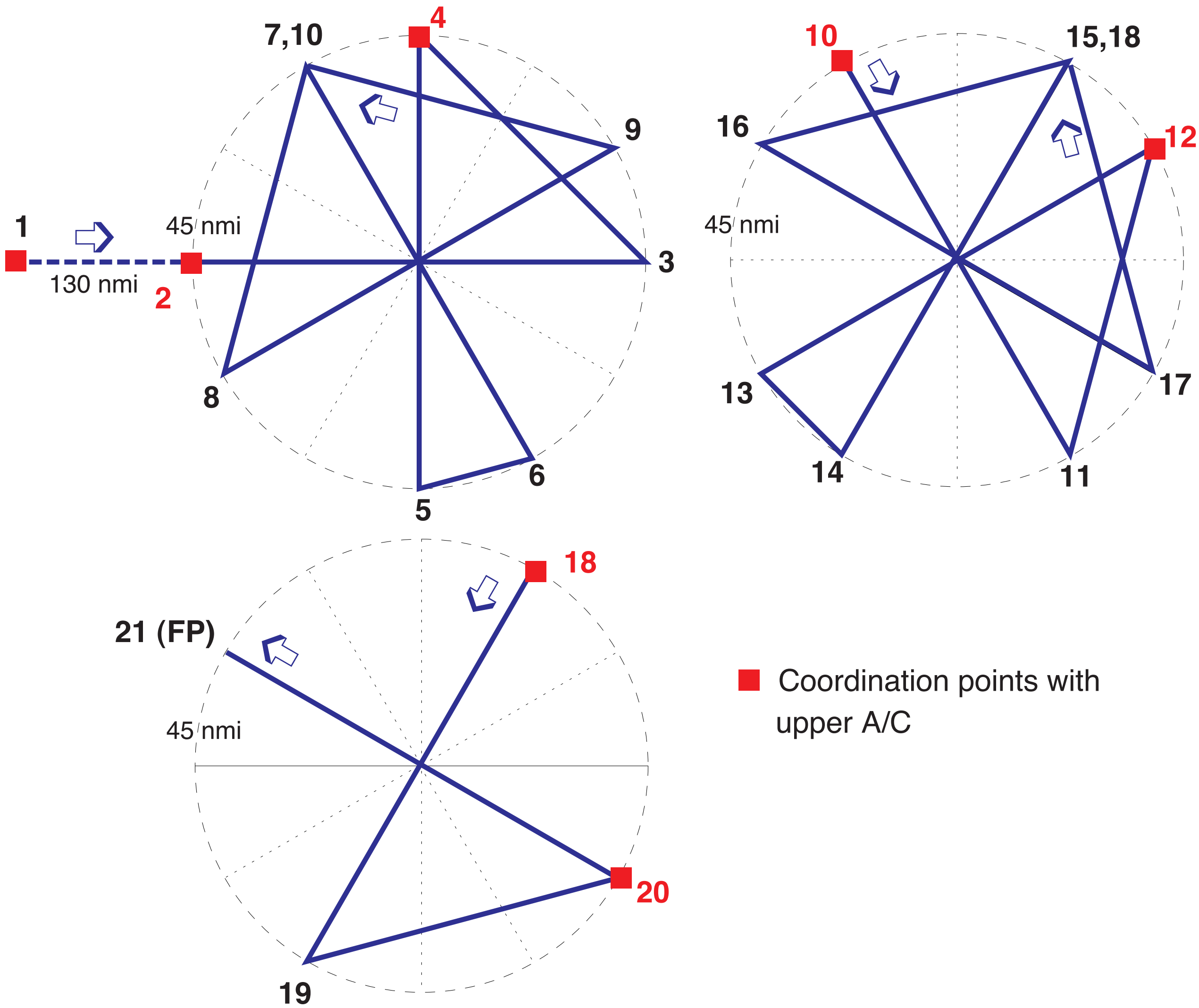


Fig. 8. Lower Aircraft Flight Pattern

- Note 1. True airspeed calibration is required.
- Note 2. Unless there is a conflict with the USAF aircraft, the lower NOAA aircraft will operate at FL 100 (10,000 ft or 3 km). The lower aircraft will drop **no** sondes.
- Note 3. The **IP** is at 130 nmi (240 km) radius from the storm center. The pattern may be entered at any compass heading, but will always be 90° upwind of the entry point of the upper aircraft. Radial legs are 45 nmi (83 km) long.
- Note 4. The **IP** and coordinating points (**CP**) must be reached simultaneously with the lower aircraft. The lower aircraft is responsible for ensuring that these points are reached simultaneously.
- Note 5. Airborne Doppler radar scans continuously perpendicular to the track on radial penetrations at radii<50 nmi (95 km) , and F/AST during the rest of the pattern.
- Note 6. Aircraft should not deviate from the pattern to find the wind center in the eye.

12. Tropical Cyclogenesis Experiment

Program Significance: The recent Tropical EXperiment in MEXico (TEXMEX) (1992) showed that the genesis of TCs in the east Pacific hurricane basin (EPAC) is a result of a complex interaction of phenomena on diverse scales. Analytical and numerical studies suggested that the principal mechanism for genesis is an enhanced latent heat flux from the sea surface that acts to elevate the mid-level equivalent potential temperature (θ_e) to the point where the downward flux of low θ_e air by evaporatively driven downdrafts is weakened and negative feedback due to cold downdrafts is reduced. A complete understanding of this process also requires a knowledge of environmental forcing of the initiating disturbance. Satellite and aircraft flight data suggest that the large scale forcing superimposed on convective scale events is an important, if not crucial, ingredient in genesis.

During TEXMEX, it appeared that the phase of the 40-50 day global oscillation, the year relative to El Nino, and the positions of both the long-wave, mid-latitude trough and associated mobile upper-level potential vorticity anomalies were important. No genesis occurred without nearby tropical wave containing a mesoscale convective systems (MCS). The MCS convection was modulated by the diurnal cycle and by fast-moving squall lines. An easterly jet at 700 mb and a southwesterly jet near the surface frequently accompanied the genesis process (similar to the synoptic-scale structure documented in the west Pacific hurricane basin (WPAC)). Intense convection occasionally developed at the southern end of rapidly moving squall lines generated near the exit region of the easterly jet. A small, intense vortex often spun up in mid-levels adjacent to the convection and built downward with time. Frequently, the surface center was initially located some distance to the west of the cloud system. Tropical-Cyclone Motion Experiments in 1992 and 1993 (TCM-92 and TCM-93) showed that MCSs associated with mid-level vortices frequently accompany genesis in WPAC, a relationship also shown by satellite climatologies. A mid- and upper-level vortex spins up in the stratiform region of the MCS, near the melting level in response to diabatically forced descent below and ascent above the melting level. This is consistent with the observations from TEXMEX, except in TEXMEX the area of interest was keyed to the 700-mb tropical wave trough axis. A number of researchers have speculated on the role of multiple interacting mid-level vortices in an incipient disturbance or wave.

The proposed experiment is designed to study incipient tropical systems which may ultimately develop into TCs. The importance of this study is not limited to TC investigations. The proposed experiment should yield useful insight into the structure, growth and ultimately the predictability of the systems responsible for the most tropical precipitation. The experiment focuses on features in the tropical atmosphere at several different levels in the vertical and on a wide range of spatial and temporal scales. These include: 1) the development of a mid-level vortex associated with MCSs at 500-700 mb, 2) role of the mid-level easterly jet in enhancing cyclonic vorticity and producing squall lines and surges at 700 mb, 3) low-level vortex spin-up in response to southwesterly surges and intense convection at cloud base. Portions of this experiment, mapping of low-level mesoscale structure and 500-mb synoptic structure, were flown successfully in dissipating Tropical-Storm Debby and Dolly during the 1994 and 1996 field program, respectively.

Objectives:

- Determination of the linkage between the synoptic-scale systems and the mesoscale vortex spinup.

- Determination of the evolution of the mid-level and low-level vorticity centers. Do multiple vorticity centers merge during the spinup process or is vertical propagation of vorticity a more important mechanism?

- Determination of how the mid-level vortex builds downward to the surface to extract latent heat from the sea.

- Determination of the role surges in the equatorial southwesterlies play in the initiation and maintenance of convection.

- Determination of the role of convection in vorticity production.

• Determination of the significance in the spinup process of the transition from dynamics driven by convectively induced cold downdrafts to non-gust front dynamics.

• Determination of the relative role in the spinup process of external forcing versus enthalpy flux from the sea and elevation of mid-level θ_e.

• Development of criteria for the genesis of a TC from a tropical wave.

Mission description: This plan calls for as many as four different mission profiles for flights into incipient disturbances or tropical waves in the western Atlantic, Caribbean, or Eastern North Pacific. The two WP-3Ds anchor the experiment flying a high-level, synoptic-scale pattern and a mid- or low-level mesoscale pattern. Collection of separate low-, mid- and high-level observations simultaneously requires an additional investigative mission by an USAF WC-130. The G-IV, if available, could provide upper tropospheric (200-300 mb) observations to study the upper tropospheric circulations.

The synoptic-scale aircraft will be a WP-3D or the G-IV. It will fly a figure-4 survey pattern at 500 mb (18,000 ft [5.5 km]) for the WP-3D or 200 mb (37,000 ft [11 km}) for the G-IV centered on the MCS (Fig. 9), but extending as far along the cardinal directions as available aircraft range allows (nominally 430 nmi [800 km]). The approach leg should be east-west to facilitate location of the trough axis. Ideally, the diagonal leg should fall in the southeast quadrant, and the south-north leg should lie at an angle to the trough axis. This aircraft will dispense 5-10 GPS-sondes and airborne expendable bathythermographs (AXBTs, WP-3D only) on each leg, including the diagonal, to map atmospheric and oceanic environment of the MCS and mid-level vortex with particular emphasis on accurate sea-surface temperature determination. The east and northeast legs should attempt to fly past the 700-mb jet into the Saharan Air Layer to obtain GPS-sonde soundings to the surface through these features. The south and southwest legs should penetrate past the low-level southeasterly jet, if it exists, in order to resolve its vertical structure with GPS-sondes. If the aircraft is a WP-3D, it should spend less than half its time under the anvil, but during that time it should collect microphysics observations and Doppler radar data using the fore/aft scanning technique (F/AST).

The mesoscale aircraft should also be a Doppler-equipped WP-3D. It will fly rotating figure-4 pattern at 600 or 700 mb (14,000 or 10,000 ft [4.2 or 3.0 km]) under the anvil of the MCS (Fig. 10). The leg lengths will be 100-135 nmi (180-250 km), and the pattern will be approximately centered on the moving trough axis. The primary purpose of this aircraft is to collect Doppler radar data using F/AST throughout the mission in order to map the three-dimensional kinematic structure of the MCS. It may dispense GPS-sondes and collect microphysics data on a target of opportunity basis.

A variation on the basic two-plane mission would add a third low-level aircraft. This aircraft flies a "racetrack" pattern at 850 mb (5,000 ft [1.5 km]) or 1,500 ft (500 m), depending on the situation (Fig. 11). If a USAF WC-130 is available, the USAF could be requested to fly a low-level investigative mission with the standard "racetrack" or "alpha" pattern. When the low-level aircraft is a WP-3D, it would fly a "racetrack" pattern oriented normal to the tropical wave trough axis. This WP-3D should have the C-band scatterometer (C-SCAT) and the stepped-frequency microwave radiometer (SFMR) for determination of the surface wind field. A low-level wind field, at either the surface or 1,500 ft (500 m) is essential for comparison with winds at upper levels in order to determine the vertical structure of the circulation features.

It would be useful to construct on-board radar composites using the workstation for more accurate positioning with respect to the MCS. GPS-sondes should be transmitted to TPC/NHC and NCEP for inclusion in synoptic analyses.

TROPICAL CYCLOGENESIS EXPERIMENT

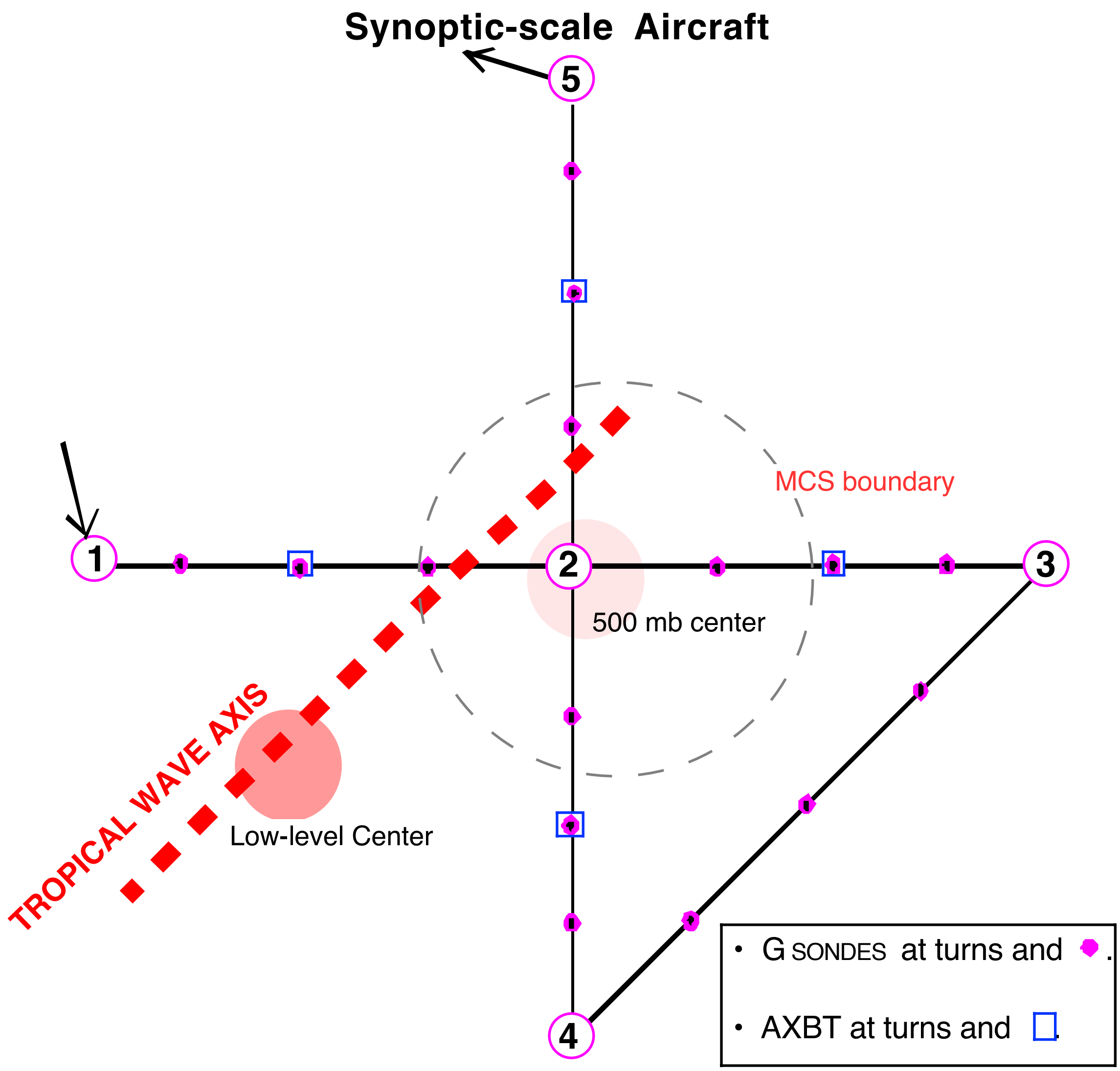


Fig. 9. Synoptic-scale Aircraft Flight Track

• Note 1.	True airspeed calibration is required.
• Note 2.	The pattern may be entered along any compass heading.
• Note 3.	Fly **1—2—3—4—2—5** at 18,000 ft (5.5 km or ~500 mb), 325–430 nmi (600-800 km) leg length, depending on ferry distance.
• Note 4.	Point 2 is near the moving apex of the trough axis.
• Note 5.	Set airborne Doppler radar to continuously scan perpendicular to the track on radial penetrations, and F/AST on downwind legs.

TROPICAL CYCLOGENESIS EXPERIMENT

Mesoscale Aircraft

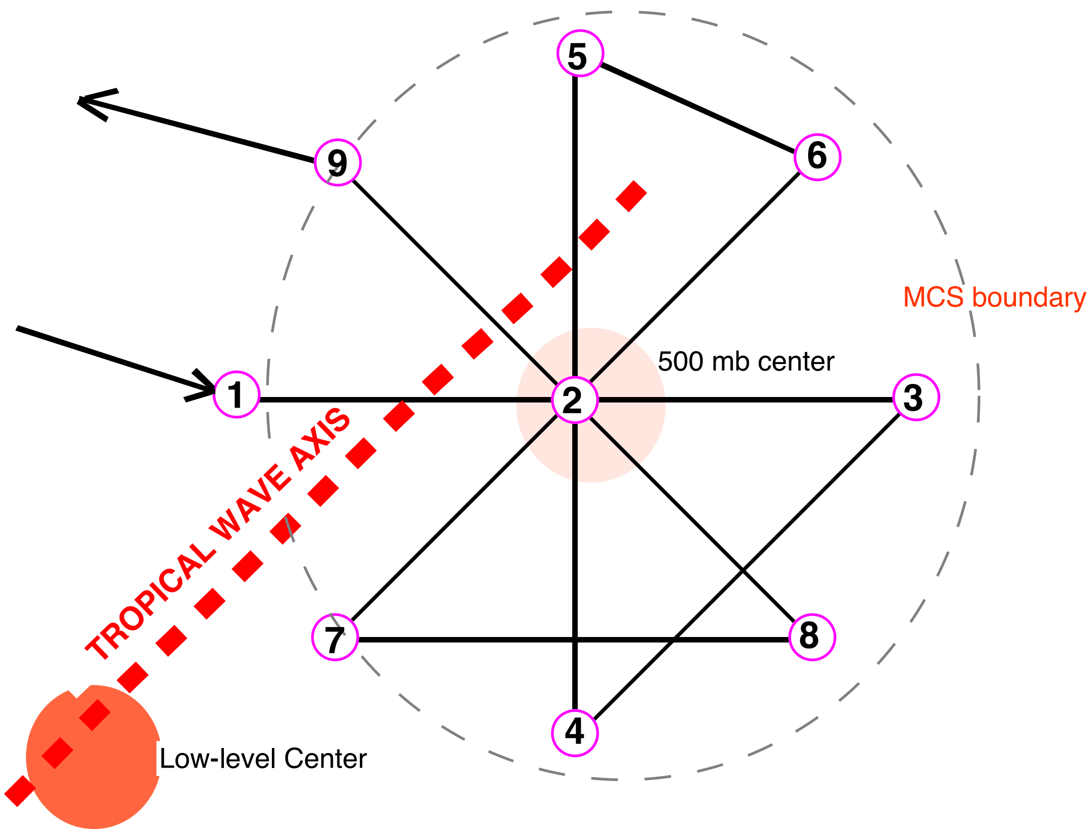


Fig. 10. Mesoscale Aircraft Flight Track

• Note 1.	True airspeed calibration is required.
• Note 2.	The pattern may be entered along any compass heading.
• Note 3.	Fly **1—2—3—4—2—5—6—2—7—8—2—9** at 600 or 700 mb (PA), 100–135 nmi (185-250 km) leg length.
• Note 4.	Point **2** is near the moving apex of the trough axis.
• Note 5.	Set airborne Doppler radar to continuously scan perpendicular to the track on radial penetrations, and F/AST on downwind legs.

TROPICAL CYCLOGENESIS EXPERIMENT

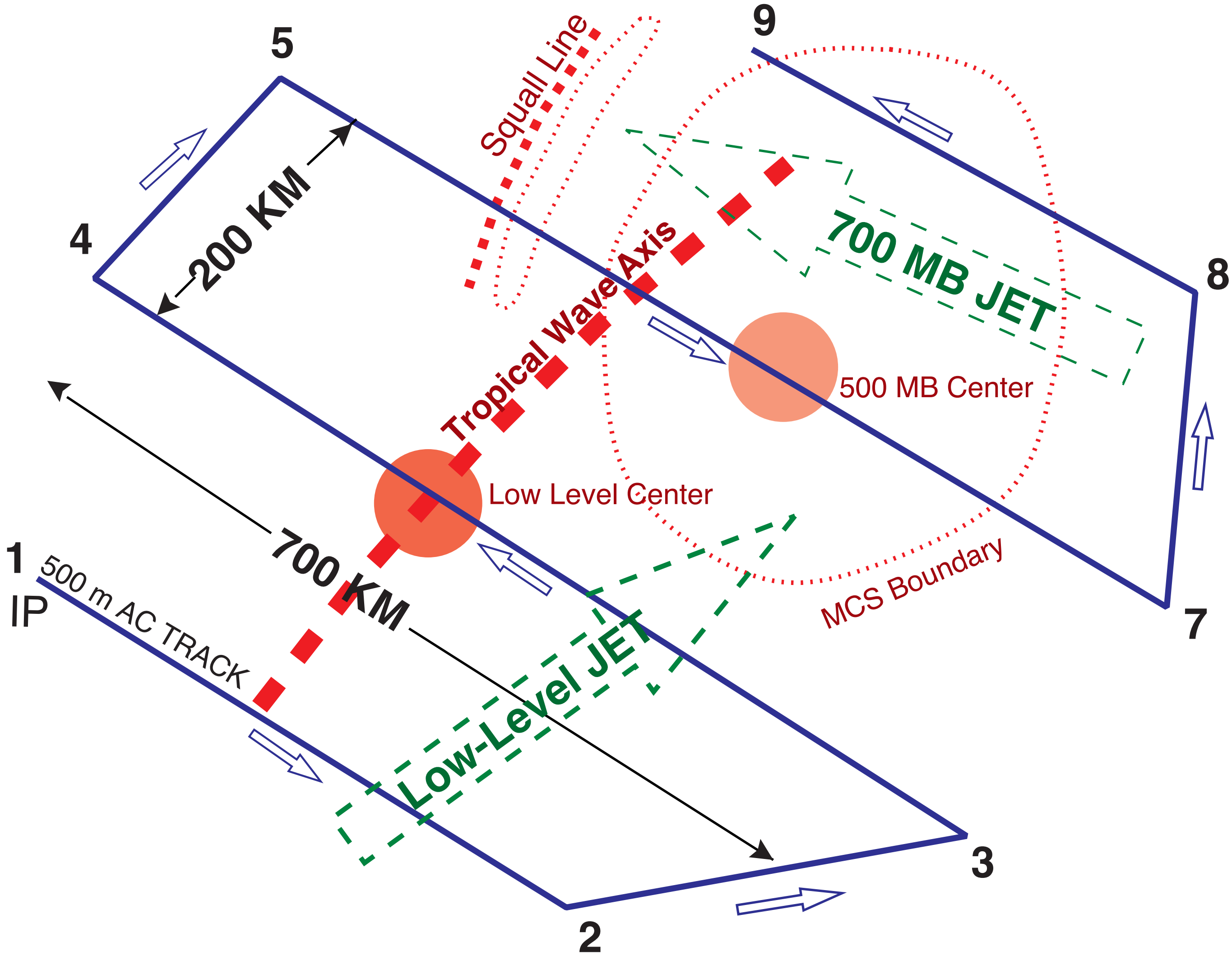


Fig. 11. Mid-level Aircraft Flight Track

• Note 1.	True airspeed calibration is required.
• Note 2.	The pattern is flown with respect to the wave axis, typically inclined at 30°–40° from N, or relative to circulation or vorticity centers.
• Note 3.	Fly **1—2—3—4—5—6—7—8—9** at 1,000 ft (300 m) or 10,000 ft (3.0 km) altitude, passing through the low–level jet, low–level circulation center (if it exists), MCS and associated mid–level center, or across mid–level jet.
• Note 4.	Set airborne Doppler radar to F/AST on all legs.

13. Tropical Cyclone Wind Fields at Landfall Experiment

Program Significance: An accurate real-time description of the TC surface wind field near and after landfall is important for warning, preparedness, and recovery efforts. During a hurricane threat, an average of 300 nmi (550 km) of coastline is placed under a hurricane warning , which costs about $50 million in preparation per event. The size of the warned area depends on the extent of hurricane and tropical storm force winds at the surface, evacuation lead-times, and the forecast of the storm's track. Research has helped reduce uncertainties in the track and landfall forecasts, but now there is an opportunity to improve the accuracy of the surface wind fields in TCs, especially near landfall.

HRD is developing a real-time surface wind analysis system to aid the TPC/NHC in the preparation of warnings and advisories in TCs. The real-time system was first tested in Hurricane Emily of 1993, but the system needs further testing before use in operational forecasts and warnings. The surface wind analyses could reduce uncertainties in the size of hurricane warning areas and could be used for post-storm damage assessment by emergency management officials. The surface wind analyses will also be useful for validation and calibration of an operational inland wind forecast model that HRD is developing under Federal Emergency Management Agency (FEMA) sponsorship. The operational storm surge model (SLOSH) could be run in real-time with initial data from the surface wind analysis.

As a TC approaches the coast, surface marine wind observations are normally only available in real-time from National Data Buoy Center (NDBC) moored buoys, C-MAN platforms, and a few ships. Surface wind estimates must therefore be based primarily on aircraft measurements. Low-level (<5,000 ft (1.5 km] altitude) NOAA and Air Force Reserve aircraft flight-level winds are adjusted to estimate surface winds. These adjusted winds, along with C-SCAT and SFMR wind estimates, are combined with actual surface observations to produce surface wind analyses. Such analyses were done after Hurricane Hugo's landfall in South Carolina and Hurricane Andrew's landfall in South Florida, as well as in real-time for Hurricane Emily's (1993) closest approach to the Outer Banks of North Carolina, and for the landfalls of Hurricanes Erin and Opal in 1995, and Fran and Josephine in 1996.

The surface wind analyses may be improved by incorporating airborne Doppler radar-derived winds for the lowest level available (~3,000 ft [1.0 km]). To analyze the Doppler data in real-time, it is necessary to use a Fourier estimation technique. The Velocity-Track Display (VTD) was developed to estimate the mean tangential and radial circulation in a vortex from a single pass through the eye. The technique was applied to Doppler data collected in Hurricane Gloria (1985) and found that the mean winds corresponded well with winds derived by pseudo-dual Doppler (PDD) analysis. The extended VTD (EVTD) was subsequently developed to combine data from several passes through the storm, resolving the vortex circulation up through the wave # 1 component. EVTD was used on data collected during six passes into Hurricane Hugo (1989) to show the development of mean tangential winds >100 kt (50 m s^{-1}) over 7 h. EVTD analyses are computed quickly on the airborne HRD workstation and could be sent to TPC/NHC shortly after their computation. The wind estimates could then be incorporated into the real-time surface wind analyses.

Dual-Doppler analysis provides a more complete description of the wind field in the inner core. While these techniques are still too computationally intensive for real-time wind analysis, the data are quite useful for post-storm analysis. An observational study of Hurricane Norbert (1984), using a PDD analysis of airborne radar data to estimate the kinematic wind field in, found radial inflow at the front of the storm at low levels that switched to outflow at higher levels, indicative of the strong shear in the storm's environment. Another study used PDD data collected in Hurricane Hugo near landfall to compare the vertical variation of winds over water and land. The profiles showed that the strongest winds are often not measured directly by reconnaissance aircraft.

By 1989 both NOAA WP-3D aircraft were equipped with Doppler radars. A study of Eastern Pacific Hurricane Jimena (1991) utilizing several three-dimensional wind fields from true dual-Doppler data collected by two WP-3D's showed that a pulse of radial wind developed in the eyewall with a corresponding decrease in the tangential winds. By the fourth pass, however, the radial pulse was gone and the tangential winds had returned to their previous value. These results suggested that the maintenance of a mature storm may not be a steady-state process. Further study is necessary to understand the role of such oscillations in eyewall maintenance and evolution.

While collection of dual-Doppler radar data by aircraft alone requires two WP-3D aircraft flying in well-coordinated patterns, a time series of dual-Doppler data sets could be collected by flying a single WP-3D toward or away from a ground-based Doppler radar. In that pattern, the aircraft Doppler radar rays are approximately orthogonal to the ground-based Doppler radar rays (Fig. 12), yielding true Dual-Doppler coverage. By 1997, the Atlantic and Gulf coasts will be covered by a network of Doppler radars (WSR-88D) deployed by the National Weather Service (NWS), Department of Defense, and Federal Aviation

TROPICAL CYCLONE WINDFIELDS NEAR LANDFALL EXPERIMENT

Groundbased/Airborne Doppler Scanning Strategy

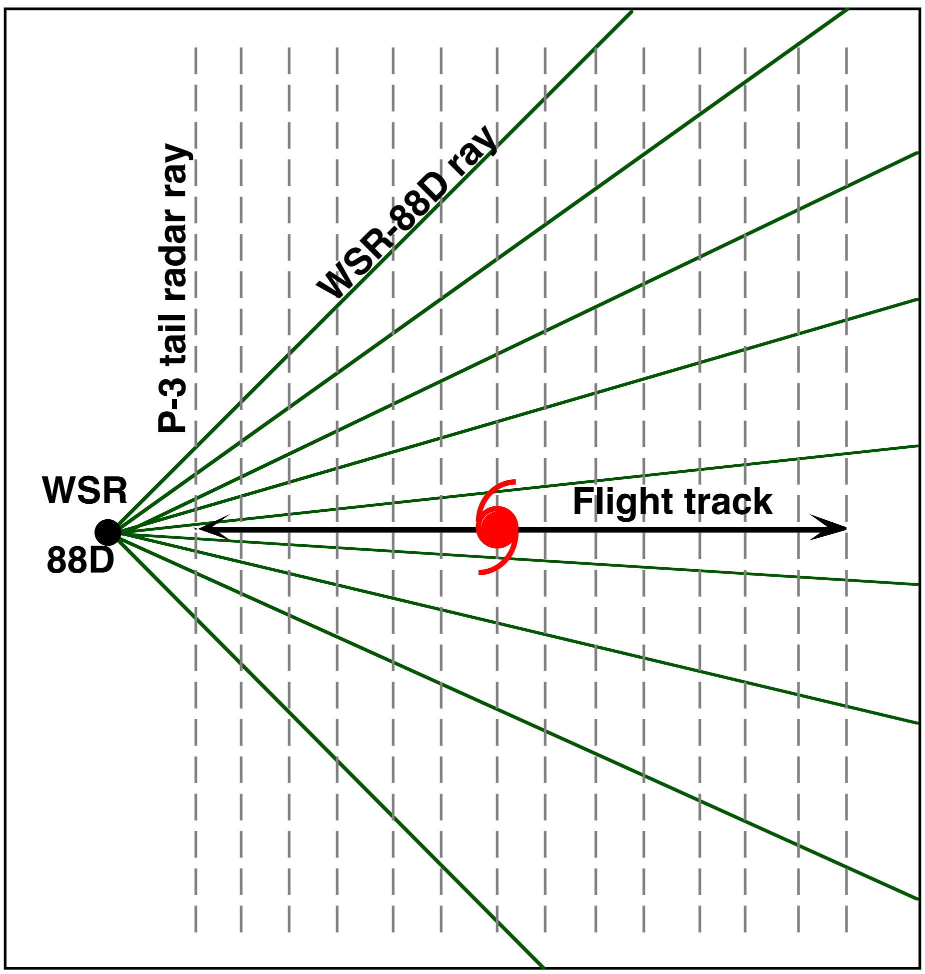


Fig. 12. Airborne Doppler Radar Flight Track

• Note 1.	The legs through the eye may be flown along any compass heading along a radial from the groundbased radar.
• Note 2.	Set airborne Doppler radar to scan continuously perpendicular to the track on all legs.

TROPICAL CYCLONE WINDFIELDS NEAR LANDFALL EXPERIMENT

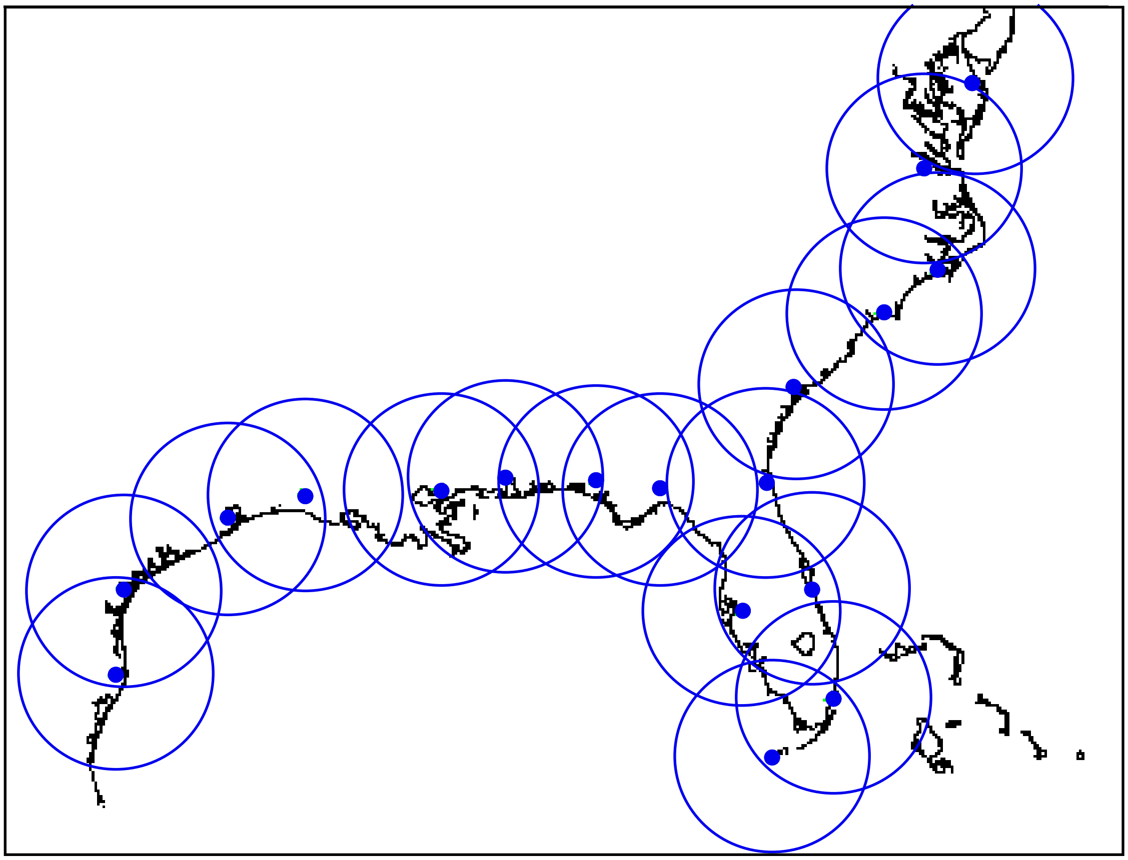


Fig. 13. The locations of the WSR–88D coastal radar sites. Range rings are at 125 nmi (230 km) radius.

Administration (Fig. 13). Each radar has a digital recorder to store the base data (Archive Level II). In precipitation or severe weather mode the radars will collect volume scans every 5-6 min.

If a hurricane or strong tropical storm (i.e., one with sufficient radar scatterers to define the vortex) moves within 125 nmi (230 km) (Doppler range) of a coastal WSR-88D Doppler radar, a WP-3D will obtain Doppler radar data to be combined with data from the WSR-88D radar in dual-Doppler analyses. These analyses could resolve phenomena with time scales <10 min, the time spanned by two WSR-88D volume scans. This time series of dual-Doppler analyses will be used to describe the storm's inner core wind field and its evolution. The flight pattern for this experiment is designed to obtain dual-Doppler analyses at intervals of 10-20 min in the inner core. Unfortunately, these WSR-88D/aircraft dual-Doppler analyses will not be available in real-time, but the Doppler wind fields could be incorporated into post-storm surface wind analyses. The data set will also be useful for development and testing of TC algorithms for the WSR-88D. The Doppler data will be augmented by dropping new GPS-sondes near the coast, where knowledge of the boundary-layer structure is crucial for determining what happens to the wind field as a strong storm moves inland.

To augment the inner core analyses, dual-Doppler data can be collected in the outer portions of the storm (where the aircraft's drift angle is small) from a single aircraft using F/AST. The tail radar is tilted to point 20° forward and aft from the track during successive sweeps. The alternating forward and aft scans intersect at 40°, sufficient for dual-Doppler synthesis of winds.

Several studies indicate that loss of the oceanic moisture source is responsible for the decay of land falling TCs. These studies relied on surface observations that are usually sparse at landfall and require time-to-space compositing techniques that assume stationarity over relatively long time periods. More complete observations could help improve our knowledge of intensity change during and after landfall. Our experience flying over the land in Hurricanes Fran over south eastern North Carolina, and Josephine over northern Florida, showed that, provided that safety requirements are met, the combination of WSR-88D observations with NOAA airborne Doppler radar and flight level measurements allow detailed documentation of the thermodynamic and kinematic structural changes to be made during landfall.

Objectives:

- Collect flight level wind data and make surface wind estimates to improve real-time and post-storm surface wind analyses in hurricanes.
- Collect single airborne Doppler radar data, analyze with EVTD, and send wind analyses in near real-time to TPC/NHC.
- Collect airborne Doppler radar to combine with WSR-88D radar data in post-storm three-dimensional wind analyses.
- Investigate the incorporation of EVTD wind fields into real-time surface wind analyses.
- Document thermodynamic and kinematic changes in the storm during and after landfall.

Mission Description: This experiment will be flown with a single aircraft if a hurricane moves within 215 nmi (400 km) of the coast of the United States. If the storm moves slowly parallel to the coastline and resources permit, the experiment may be repeated with a second flight. The aircraft must have working lower fuselage and tail radars. The HRD workstation should be on board, so we can transmit radar images and an EVTD analysis back to TPC/NHC. Microphysical data should be collected, to compare rainfall rates with those used in the WSR-88D precipitation products. The SFMR should be operated, to provide estimates of wind speed at the surface. If the C-SCAT is on the aircraft then it should also be operated to provide another estimate of the surface winds. If the storm will be within 125 nmi (230 km) of a WSR-88D, arrangements must be made to ensure that Level II data are recorded.

If the portable Doppler radars (Doppler on Wheels—DOW) and/or portable profilers are able to participate in the experiment then they should be deployed to the region forecast to be outside of the eyewall, in the onshore flow regime. If possible the DOW should be positioned relative to the nearest WSR-88D such that the dual-Doppler lobes cover the largest area of onshore flow possible. In the examples shown below the DOW is positioned north of the Melbourne WSR-88D so that one dual-Doppler lobe is over the coastal waters and the other covers a region ~50-100 km inland. The profiler is positioned in the inland dual-Doppler lobe to provide independent observations of the boundary layer to anchor the dual-Doppler analysis.

The primary module of the experiment, the "real-time module", will support real-time and post-storm surface wind analyses. Two dual-Doppler options can be flown if the storm is near a WSR-88D radar. A coastal-survey option can be flown when the storm is too close to the coast to permit radial penetrations. The flight patterns will depend on the location of the storm relative to surface observing platforms and coastal radars.

Real-time module: The real-time module combines passes over marine surface platforms with one or more figure four patterns in the core of the hurricane. The aircraft flies at or below 5,000 ft (1.5 km) (ideally at 2,500 ft [750 m]), so that flight level winds can be adjusted to 30 ft (10 m) to combine with measurements from marine surface platforms. Flight-level data and GPS-sondes dropped near the platforms will be used to validate the adjustment method. Doppler data collected in the figure four will be analyzed with EVTD in real-time on the HRD workstation. The lowest level of the EVTD analysis may be sent to TPC/NHC where the Doppler winds can also be adjusted to the surface and made available to HRD's real-time surface wind analysis system. Note that if the storm is outside of WSR-88D Doppler range then the figure four pattern could be repeated before returning home.

For example, if a hurricane moves within range of Melbourne, Florida, then the flight pattern should take advantage of buoys 41009 and 41010. The aircraft descends at the initial point and begins a low-level figure-4 pattern, modifying the legs to fly over the buoys (Fig. 14). Whenever the drift angle permits the radar will be in F/AST mode, except in the eye penetrations. If time permits the aircraft would make one more pass through the eye and then fly the dual-Doppler module. In this example the pattern would be completed in about 2.5 h. GPS-sondes would be dropped near the buoys.

Dual-Doppler Option 1: If the TC moves within Doppler range of a coastal WSR-88D 125 nmi (230 km), then we will fly a second module, to collect a time-series of dual-Doppler data from the storm's inner core. Note that the optimal volume scans for this pattern will be obtained when the storm is 32-80 nmi (60-150 km) from the radar, because beyond 80 nmi (150 km) the lowest WSR-88D scan will be above 5,000 ft (1.5 km) which is too high to resolve the low-level wind field. Within 32 nmi (60 km) the volume scan will be incomplete, because the WSR-88D does not scan above 19.5°.

The pattern will depend on the location of the storm relative to the coastal radar. Depending on safety and operational considerations, the aircraft could fly this portion of the experiment at a higher altitude, although 5,000 ft (1.5 km) would still be preferred. Continuing our example for the Melbourne WSR-88D, after completing the real-time module the aircraft flies to an initial point on the track intersecting the storm center and the coastal radar (Fig. 14). The aircraft then makes several passes through the eyewall (**A-B** in Fig. 14), with the tail radar scanning perpendicularly to the track. Depending on the size of the eyewall each pass should last 10-20 min. It is essential that these passes be flown as straight as possible, because turns to fix the eye will degrade the Doppler radar coverage. After each pass the aircraft turns quickly and heads back along the same track, adjusted to keep the storm center and the coastal radar on the same line. In 2 h, 6-12 volume scans will be collected. The last pass should be followed by a pass through the eye perpendicular to the other legs, to provide data for EVTD and pseudo-dual Doppler analyses. If time permits, the real-time module could be repeated before returning home, or the coastal-survey module could be flown.

Dual-Doppler Option 2: If dual-Doppler data are desired over a larger area, then another module will be flown where the aircraft flies along three WSR-88D radials to survey both the inner core and surrounding rainbands (Fig. 15). In the example shown, this pattern could be flown in about 2 h. Note that the legs outside the inner core should be flown with the tail radar in F/AST mode because the drift angle would be smaller. In the example the module concludes with a coastal-survey pass south along the coast.

Coastal Survey option: When the hurricane is making landfall, this module will provide information about the boundary layer in the onshore and offshore flow regimes. The WP-3D would fly a coastal survey pattern parallel to the coast, as close as safety permits, at 5,000 ft (1.5 km) or less, and drop GPS-sondes on either side of the storm track, to sample both onshore and offshore flow regimes (Fig. 16). The Doppler radar would be in F/AST mode, to provide wind estimates on either side of the aircraft track. This module could be flown when the hurricane is making landfall or after the storm moves inland. The pattern could be flown in ~1 h. GPS-sonde drops could be adjusted to be near surface platforms.

Post-landfall option: If the structure of the storm is such that flight patterns at 10,000 or 15,000 ft (3.0 or 4.5 km) are feasible over land, the pattern shown in Dual Doppler option 1 would be flown, except that the storm would be followed inland as long as time and safety considerations permit. It may be possible to fly the radial legs with the radar in F/AST scanning mode depending on the location and status of the WSR-88D.

TROPICAL CYCLONE WINDFIELDS NEAR LANDFALL EXPERIMENT

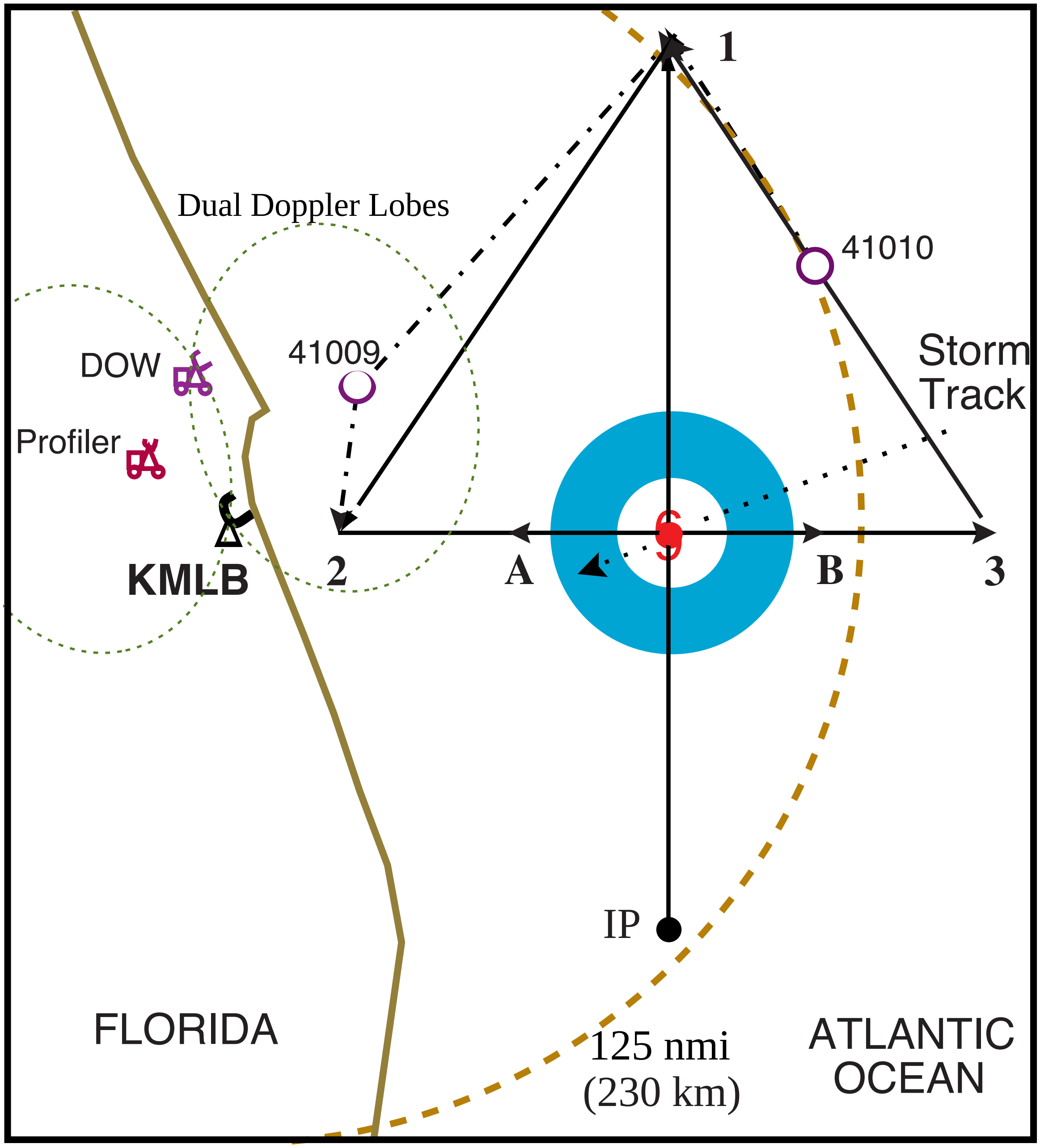


Fig. 14. Flight track for the real-time module with overflights of moored buoys for a storm passing within range of a coastal WSR-88D.

- Note 1. True airspeed calibration required.
- Note 2. The legs through the eye may be flown along any compass heading along a radial from the ground-based radar. The **IP** is approximately 100 nmi (185 km) from the storm center. Downwind legs may be adjusted to pass over buoys.
- Note 3. Dual-Doppler sampling is along a radial from the WSR-88D radar (**A-B**) and may be repeated a number of times.
- Note 4. Set airborne Doppler radar to scan continuously perpendicular to the track on radial penetrations, and to F/AST on all downwind legs.

TROPICAL CYCLONE WINDFIELDS NEAR LANDFALL EXPERIMENT

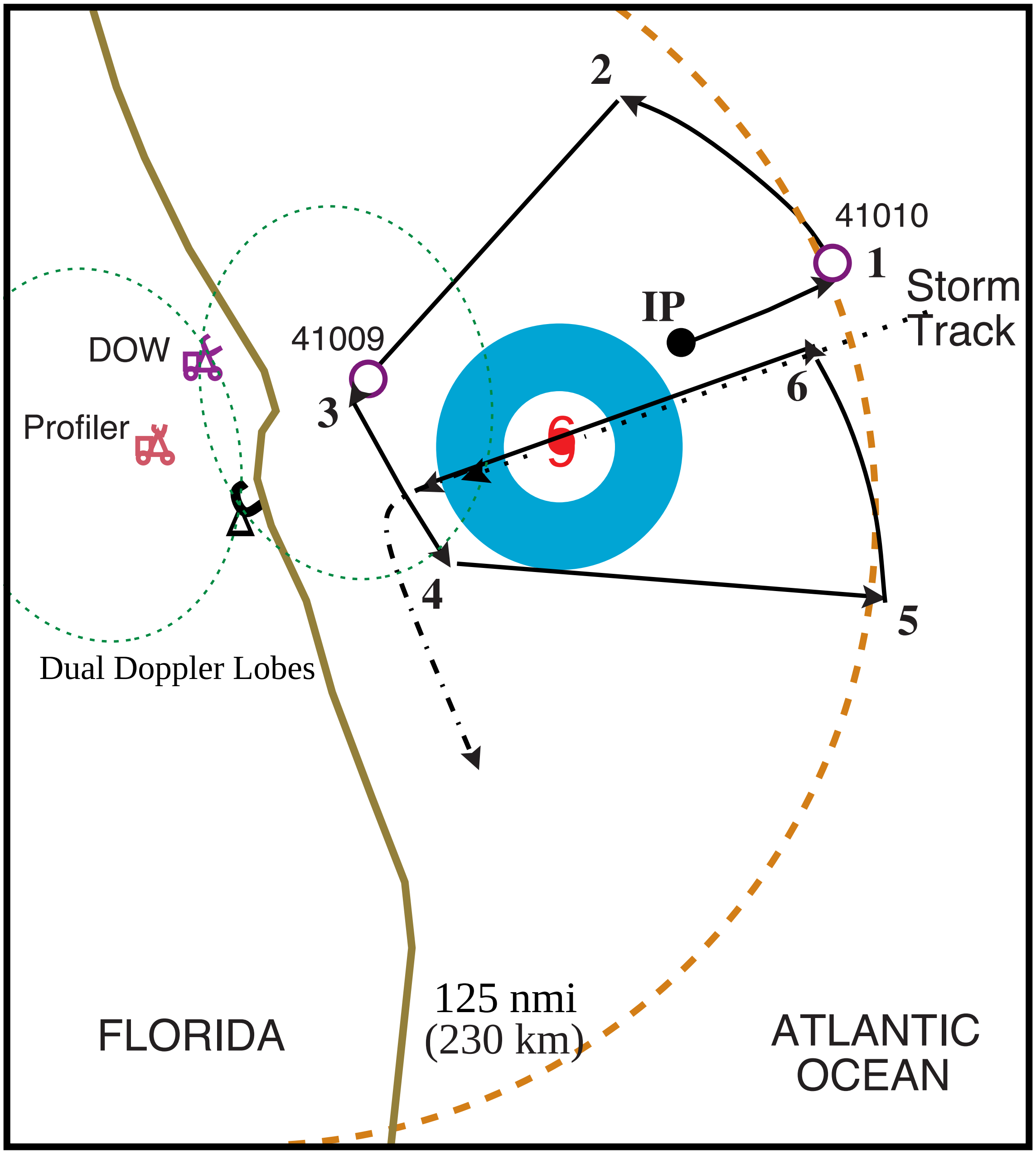


Fig. 15. Flight track for the dual-Doppler option that covers the inner core and surrounding rainbands.

• Note 1.	True airspeed calibration required.
• Note 2.	The legs through the eye may be flown along any compass heading along a radial from the ground-based radar. The **IP** is at the end of the last leg in the real-time module. Downwind legs may be adjusted to pass over buoys.
• Note 3.	Dual-Doppler sampling is along a radial from the WSR-88D radar (**A-B**) and may be repeated a number of times.
• Note 4.	Set airborne Doppler radar to scan F/AST on all legs except from **IP-1**.

TROPICAL CYCLONE WINDFIELDS NEAR LANDFALL EXPERIMENT

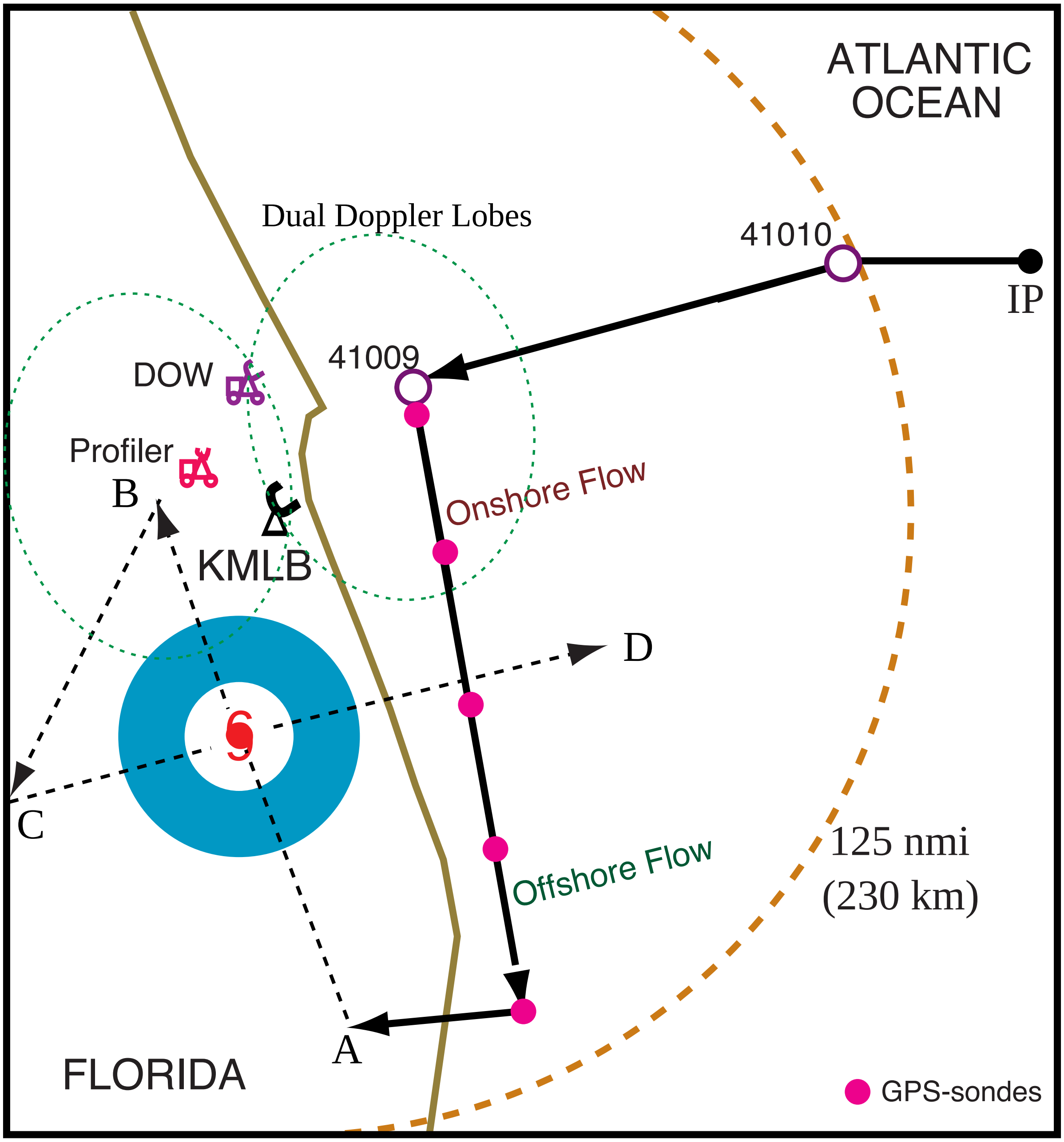


Fig. 16. Flight track for the real-time module with overflights of moored buoys and GPS-sonde drops for a storm after landfall.

• Note 1.	Begin pattern after execution of the coastal survey option. Execute figure-4 or triangle pattern on circulation center with ~60 nmi (110 km) legs at 14,000 ft (4 km) altitude (dashed line).
• Note 2.	GPS-sondes should be dropped at least 10 nmi (18 km) offshore in the onshore flow regime, and as close as possible to the coast in the offshore flow regime.
• Note 3.	Avoid penetration of intense reflectivity or reflectivity gradient areas. Wind center penetrations are optional.
• Note 4.	If possible the legs of the pattern should be lined up on WSR-88D radials. Set airborne Doppler radar to F/AST scanning on all legs.

14. Tropical Cyclone Air-Sea Interaction Experiment

Program Significance: This experiment examines the relationship between TC intensity change and changes in the underlying sea surface temperature (SST) through two types of interactions with the underlying sea surface: (1) Changes in SST due to translation of the storm over pre-existing ocean features; and (2) Changes in SST induced by the TC itself. In the case of (1), three types of features will be examined: (a) permanent, such as the Gulf Stream and Gulf Loop Current, (b) semi-permanent, such as Gulf of Mexico Warm Eddies (GOMWEs) and (c) transitory, such as cold wakes from previous TC's. Underlying SST and Mixed Layer Depth (MLD) changes for the above conditions result in changes of surface maximum wind, surfaced wind field structure, distribution of eyewall and rainband convective activity, rainfall, minimum surface pressure, and thermodynamic structure of the inflow layers. The extent to which these changes can be separated from other external environmental forcing factors, such as mid-latitude troughs and sub-tropical jet streams is the subject of this experiment. While a viable experiment in its own right, this experiment is best run in concert with other single-aircraft experiments such as the XCDX experiment and a G-IV synoptic surveillance mission. The combination of these three experiments are a key ingredient in assessing the importance of internal storm dynamics and environmental interactions on storm intensity change concurrent with air-sea interaction measurements.

It is an important national priority to improve the forecasts of surface wind field intensity, structure and storm surge in landfalling TCs in order to successfully mitigate the detrimental physical impacts associated with these storms. Coastal population growth in the U.S. of 4-5% per year, is outpacing the historic 1-2% per year rate of improvement in official hurricane track predictions. While specific track prediction models have indicated up to a 15% improvement over the past 2-3 years, very little skill has been shown in the prediction of intensity change or wind field distribution. For this reason, the average length of coastline warned per storm, about 570 km, has not changed much over the past decade, nor has the average overwarning percentage, about 75%. However, the average preparation costs have increased eight-fold in the past 7 years from $50M per storm in 1989 to an estimated $300M per storm in 1996, or about $640K per mile of coastline warned.

Forecasters from the three American TC forecast centers, The National Hurricane Center (NHC), the Central Pacific Hurricane Center (CPHC) and the Joint Typhoon Warning Center (JTWC), have recommended that their highest priority in hurricane research is the improvement in hurricane wind field and intensity forecasting. The Hurricanes at Landfall (HaL) program has been created to improve the analyses and forecasts of the pattern, extent and intensity of damaging winds associated with landfalling TCs in order to bring about a reduction in the current overwarning percentage and an increase in the damage mitigation.

A major source of difficulty in past efforts to predict hurricane intensity, wind fields and storm surge at landfall has been the inability to measure the surface wind field directly and the inability to predict how it changes in response to external and internal forcing. The surface wind field, defined as the radius of maximum winds and the radii of hurricane force, 26m s^{-1} and 18m s^{-1} force winds in each quadrant of the TC, must presently be estimated from a synthesis of scattered surface ship and/or buoy observations and aircraft measurements at 1.5 km to 3.0 km altitude. This task is complicated by variations with height of the storms' structure, such as the change with height of storm-relative flow due to environmental wind shear and to the variable outward tilt of the wind maximum with height.

Direct linkages between TC intensity change and observed air-sea changes have been difficult to make since many storms are also exposed to tropospheric environmental influences. In addition, detailed oceanographic and surrounding environmental observations in the atmosphere have been generally lacking from which to make comparisons. Thus, it is a primary goal of this study to establish the link, statistically and physically, between changes in air-sea interaction processes brought about by changes in oceanic features and changes in the TC surface wind field.

To partially overcome these past difficulties, we propose a mobile observing strategy comprised of a mix of in-situ air-deployed surface and subsurface sensors, and airborne remote sensors allowing the surface wind field to be directly measured. We postulate that knowing the surface wind field at landfall is the most important component of HaL for improving, not only wind warnings, but storm surge estimates and estimates of the rate of inland wind field decay. We further postulate that to improve these estimates we must know, not only the wind field itself, but the tendency in the wind field, that is, whether it is strengthening, weakening, broadening or shrinking. It has been generally agreed that changes in the wind field will be brought about by (1) changes in the large-scale environmental conditions, (2) changes in the underlying boundary and (3) naturally-evolving internal dynamics.

Several dramatic cases suggesting a strong role of air-sea interaction processes on TC intensity changes have occurred in recent years, many of which have been landfalling situations, where intensity change forecasting is especially crucial. Hurricane Andrew (1992) gained strength as it passed over the Gulf Stream just before landfall on South Florida. In over half of the 32 storms that occurred during the 1995 and 1996 hurricane seasons, significant intensity changes were associated with storm translation over SST boundaries, which were either pre-existing or created by previous storms. Many of these storms also experienced interactions with mid-latitude troughs during the same time period, which has made it difficult to partition the physical processes responsible for the observed intensity changes. The goal of the present study is to establish the link, statistically and physically, between changes in air-sea interaction processes and observed intensity changes.

Objectives: The specific goal of this experiment is to improve the analysis and forecasting of the surface wind field and oceanic response, including storm surge, in landfalling TCs by understanding relevant air-sea interaction processes. In order to achieve this goal, we must:

1) Determine the relationship between changes in the TC surface wind field and changes in the offshore upper ocean structure along its path for time periods before, during and after TC passage over oceanic features near landfall.

2) Determine the relationship between changes in the TC surface wind field and changes in air-sea fluxes.

3) Determine the interaction between the wind field, waves, currents and water-level in generating storm surge at landfall.

4) Incorporate air-sea fluxes, influences of upper oceanic circulations, and interactions between the wind field, waves and storm surge into model initialization, verification and parameterization to improve the TC coastal wind forecasts.

Initial expectations over the next few years are:

- A real-time surface wind remote sensing algorithm and wind field analysis package.

- A statistical relationship between storm intensity change and lower tropospheric/upper ocean variables.

- An improved understanding of the oceanic mixed layer response to TC forcing in the presence of variable background features.

- Determine the extent to which Atmospheric Boundary layer (ABL) maintenance is controlled by Sea Surface Temperature (SST) distribution, mesoscale and convective-scale downdrafts, rainfall evaporation, and between-band subsidence.

- A more accurate representation of air-sea fluxes in the TC ABL.

- Improvements in our understanding of hurricane generated waves and currents in the deep ocean, over the shelf, and in the near shore region. This information in addition to the better depiction of the wind field can improve the model inputs for storm surge modeling and forecast efforts.

- Improvements of existing ABL parameterizations in numerical hurricane models that are being developed for forecast applications.

The achievement of these goals is important to NOAA's mission to improve hurricane forecasts and warnings on both the short and long-term time scales. In the short-term, this investigation seeks to provide real-time measurements of winds at the surface and at typical aircraft flight-levels. In the long term, improved understanding of the behavior of the hurricane ABL over the ocean and near landfall will lead to improvements in dynamical model predictions and to improved initial data for storm surge models.

Mission Description. While a viable experiment in its own right, this experiment is best run in concert with other single-aircraft experiments such as the XCDX experiment and a G-IV synoptic surveillance mission. The combination of these three experiments are a key ingredient in determining what portion of the observed intensity change is a result of internal storm dynamics, large scale environmental forcing, and oceanic forcing. The TC Air-sea Interaction Experiment seeks to measure the surface wind field structure concurrently with the oceanic feature structure using NOAA WP-3D aircraft flights within the TC during three time periods:

1) **Pre-landfall**: (48 -36 h before landfall; one aircraft)
   During the Pre-landfall portion of this experiment one WP-3D aircraft with AXBT/AXCP launching capability is required to map the upper ocean boundary layer structure in a (pre-determined) ocean feature ~48 h prior to landfall or ~36 h before TC/ocean feature interaction occurs. The Pre-landfall flight patterns outlined in Figs. 17a and 17b (for either symmetric or asymmetric ocean features) are designed to accurately measure the ocean feature's undisturbed structure. Another single aircraft experiment, such as XCDX, is to be conducted at the same time as, or immediately following, the Pre-landfall flight segment to accurately measure internal storm structure prior to TC/ocean feature interaction. This flight should be coordinated with a G-IV synoptic surveillance mission in the environment surrounding the TC.

2) **Near-landfall:** (12-24 h before landfall; one aircraft)
   During the near-landfall phase a single WP-3D aircraft with AXBT/AXCP launch capabilities is required. The flight plan ,outlined in Fig. 18, commences as the TC begins to interact with either the symmetric or asymmetric ocean feature (i.e., ideally ~12-24 h prior to landfall). As in the Pre-landfall mission, the Near-landfall mission should also be coordinated with a G-IV synoptic surveillance mission in order to determine environmental influences on the TC.

3) **Post-landfall**: (24 h after landfall; one aircraft)
   The final phase of this experiment requires a single aircraft with AXBT/AXCP launch capabilities. This flight, which is to occur ~ 24 h after TC landfall, is designed to survey the ocean feature's 'post storm' structure. The post-landfall flight plan is identical to the pre-landfall flight patterns illustrated in Figs. 17a and 17b, except **no** GPS drops or mini-buoy platforms are required for the post landfall survey.

The Pre-landfall period defines the initial conditions for model predictions, while the Near- and Post-landfall periods are used for model validation.

Operational reconnaissance flight-level data from AFRES WC-130 aircraft are used throughout the Pre- and Near-landfall periods to assess the role of internal dynamics in modifying TC wind fields. At least three drifting buoy platforms should be deployed by AFRES WC-130 aircraft prior to, or at the beginning of, either the Pre-landfall mission or the Near-landfall mission, depending upon feature location relative to the coast.

To conduct these experiments, the WP-3D should have working lower fuselage and tail Doppler radars, SFMR, C-SCAT/profiler, GPS dropwindsonde system, AXBT/AXCP instrumentation, nose, vertical, and side-looking video cameras are required. Sufficient GPS sondes and AXBTs and/or AXCPs (if available) must be carried to perform the drops noted in each option. The availability of an airborne Doppler radar on both WP-3D aircraft and the addition of the SFMR and C-SCAT for high-resolution measurements of surface wind speed and rain rate. The GPS sondes, AXBTs, AXCPs and the radome-mounted gust probe (with Lyman-a and Rosemount temperature sensors) insure that valuable supporting data on air-sea stability and turbulent fluxes are obtained.

TROPICAL CYCLONE AIR-SEA INTERACTION EXPERIMENT

Pre-Landfall Symmetric Ocean Feature Module

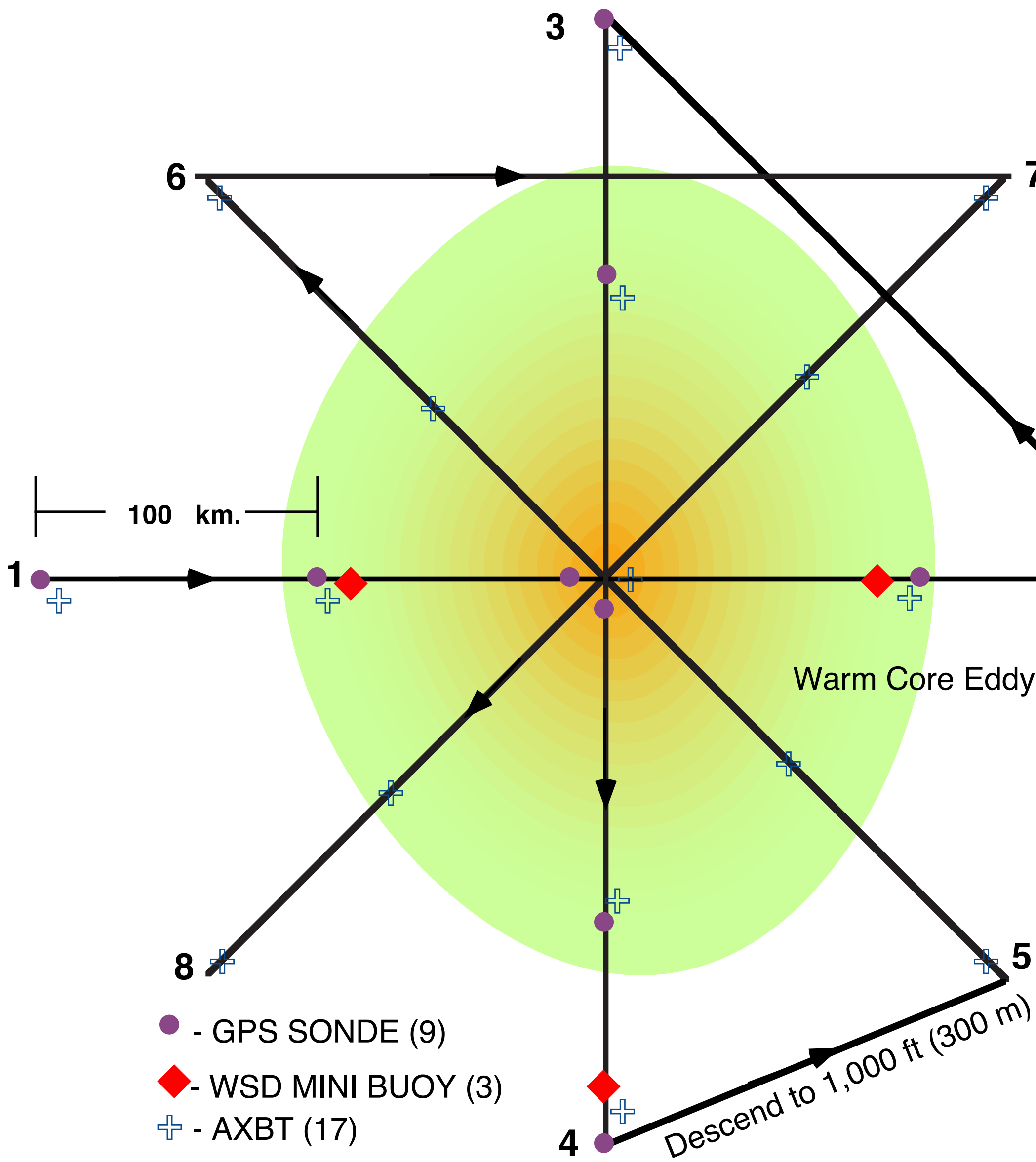


Fig. 17. (a) Pre-landfall symmetric ocean feature survey pattern

• Note 1.	A/C Flies **1-2-3-4** at 5,000 ft (1,500 m) and **5-6-7-8** at 1,000 ft (300 m). Each leg is 200 km radius from the center of the eddy.
• Note 2.	Display specific humidity and θ_e on 1-s display and 10-s listing.
• Note 3.	Set airborne Doppler radar to continuously scan perpendicular to the track on all radial penetrations, and F/AST on downwind legs.
• Note 4.	Mini-buoys (WSDs) are to be deployed by Air Force prior to/at the beginning of the experiment

TROPICAL CYCLONE AIR-SEA INTERACTION EXPERIMENT

Pre-Landfall Asymmetrical Ocean Feature Module

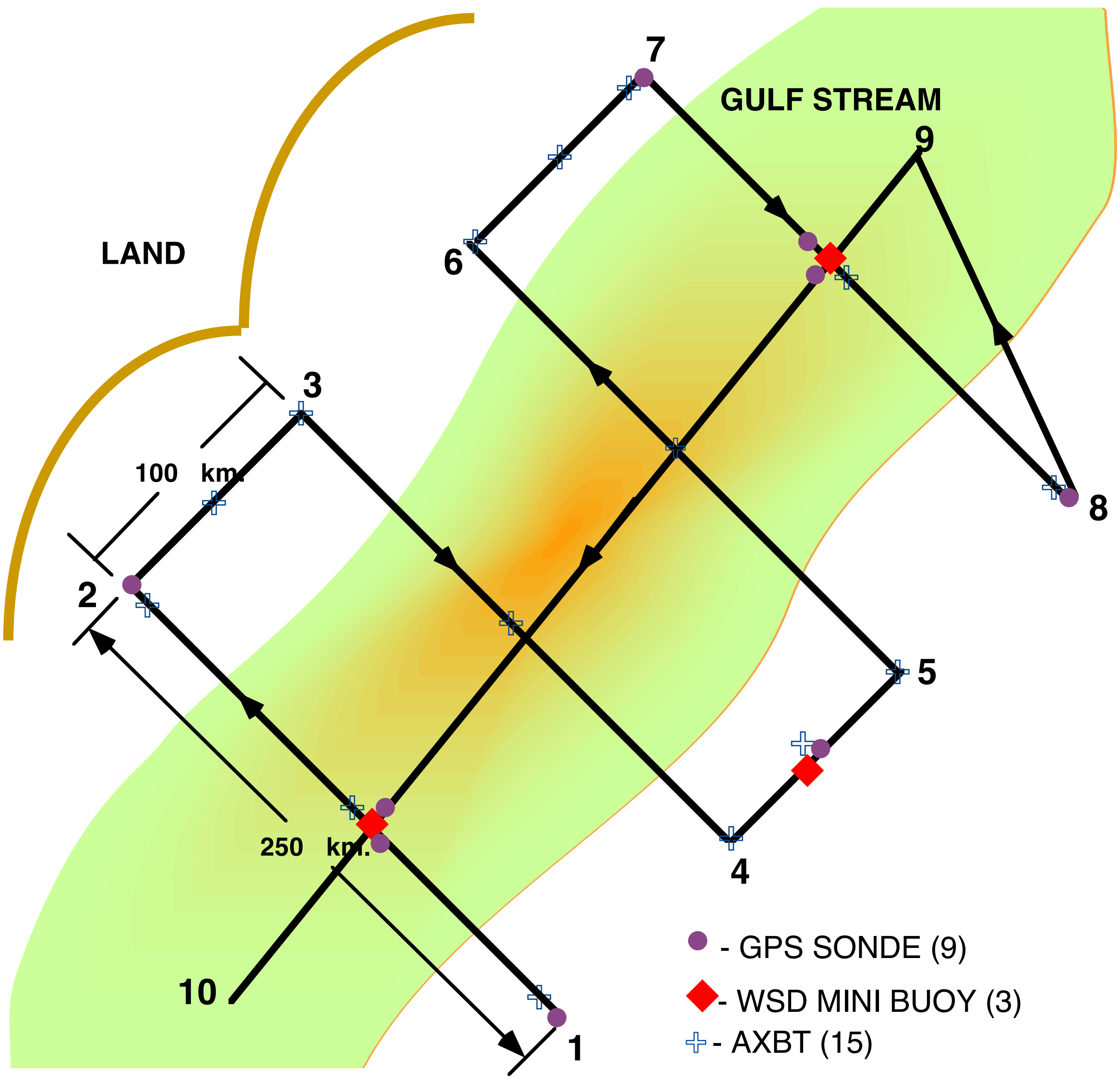


Fig. 17. (b) Pre-storm asymmetric ocean feature survey pattern

- Note 1. A/C Flies **1-2-3-4-5-6-7-8-9-10** at 5,000 ft (1,500 m).
- Note 2. Display specific humidity and θ_e on 1-s display and 10-s listing.
- Note 3. Set airborne Doppler radar to continuously scan perpendicular to the track on all radial penetrations, and F/AST on downwind legs.
- Note 4. Mini-buoys (WSDs) are to be deployed by Air Force prior to/at the beginning of the experiment

TROPICAL CYCLONE AIR-SEA INTERACTION EXPERIMENT

Near-Landfall Survey Module

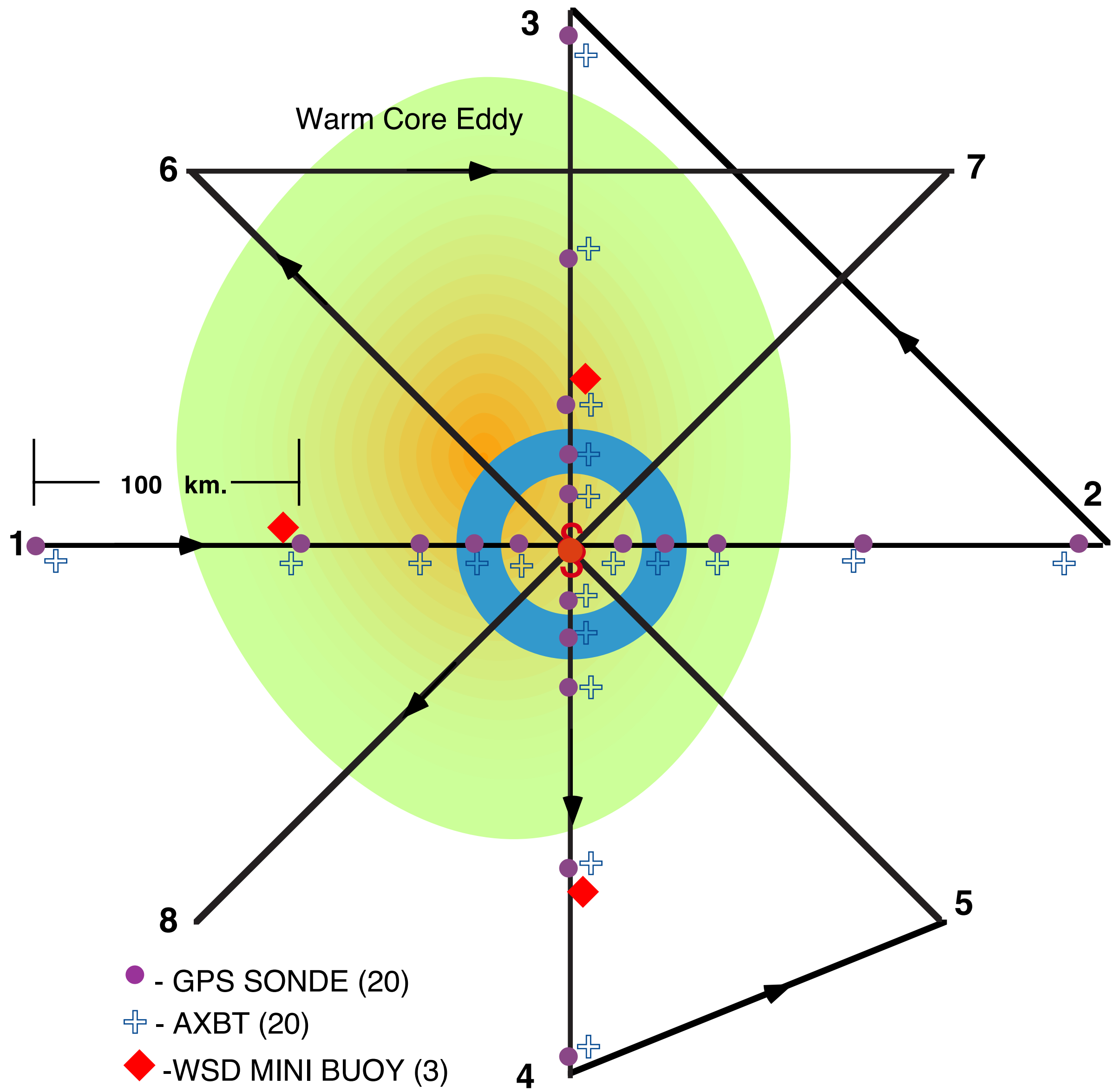


Fig. 18. Near-landfall survey pattern

• Note 1.	Fly **1-2-3-4-5-6-7-8** at 5,000 ft (1.5 km). Each leg is 200 km radius from the storm center.
• Note 2.	Drop 10 GPS sondes and 10 AXBTs each along legs **1-2** and **3-4**, one GPS sonde and AXBT on each end of the leg, 100 km from each end of the leg, just outside the eyewall, in the eyewall, and just inside the eye.
• Note 4.	Set airborne Doppler radar to continuously scan perpendicular to the track on all radial penetrations, and F/AST on downwind legs.
• Note 5.	If mini-buoys are present attempt to coordinate with GPS drops.

15. Rainband Structure Experiment

Program Significance: Over the past few decades, the hurricane inner core (specifically the eyewall region), has been studied extensively. Numerous aircraft observations have been gathered and many computer models have been developed and run to better understand tropical cyclones. An area of research which has been somewhat neglected over the same time period is that of hurricane rainbands.

Spiral-shaped patterns of precipitation characterize radar and satellite images of tropical cyclones. The earliest radar observations of tropical cyclones detected these bands, which are typically 3-36 nmi (5-50 km) wide and 55-160 nmi (100-300 km) long. Nevertheless, many aspects of their formation, dynamics, and interaction with the symmetric vortex are still unresolved. The precipitation-free lanes between bands tend to be somewhat wider than the bands. The trailing-spiral shape of bands and lanes arises because the angular velocity of the vortex increases inward and distorts them into equiangular spirals. As the tropical cyclone becomes more intense, the inward ends of the bands approach the center less steeply approximating arcs of circles. A dynamical distinction exists between convective bands that spiral outward from the center and convective rings that encircle the center.

The detailed case studies which have been accomplished have revealed important aspects of rainbands that were previously unknown. They identified the 'principal band' as a frequent and persistent feature in tropical cyclones. Based on the rainband structure determined by these early studies, it was hypothesized that certain rainbands may be able to thermodynamically modify air that attempts to cross a band. Recent studies found a 20°K decrease in low-level qe in a rainband downdraft, and suggested that the draft acted as a barrier to inflow. It was noted that the reduction in boundary-layer energy may inhibit convection near the center. While these case studies have discussed rainbands as important features of the hurricane circulation and have inferred a relationship between their existence and the hurricane weakening, very little research has attempted to analyze a large data base of observations from several rainbands. Recent analyses of a large database of radial legs associated with convectively-active rainbands found their kinematic structure were very similar to that of the eyewall. Further, these analyses showed that an outer rainband could provide a barrier to inflowing moist air, and that it is possible that the air may be thermodynamically modified.

At times, rainbands form into full rings that surround the eyewall of the hurricane. The interaction between the two 'concentric' rings has been shown to be associated with the weakening of hurricanes. As the outer ring contracts around the inner, the inner eyewall collapses frequently causing a marked weakening of the storm. While this relationship between concentric eyewalls and intensity has been identified, the physics responsible for these changes are poorly understood as we lack both kinematic and thermodynamic measurements in concentric eyewalls necessary to identify how and why they form and how they affect intensity.

The lack of rainband observations leaves us to infer and assume critical elements of rainband structure that may be of fundamental importance to our understanding of the tropical cyclone. It seems clear that concentric eyewalls can affect hurricane intensity, and available evidence suggests that convectively-active non-concentric rainbands may play a role in the intensity changes in the hurricane core. It is extremely important that we understand the structure of rainbands and secondary eyewalls and how they may impact the hurricane environment. This experiment is designed to address these issues by gathering kinematic data in and around hurricane rainbands. In addition, with the new GPS-sondes, it is possible to sample some the thermodynamic aspects of the hurricane boundary layer.

Objectives: The general goal of this experiment is to document the structure of non-concentric and concentric rainbands and the environment both inside and outside bands. Data sets from this experiment will be used to determine whether rainbands provide a barrier to the inflow of moist air to the eyewall. Data gathered in this experiment will also allow investigation of the possible thermodynamic effects the rainband may have on the hurricane environment. Specific goals include:

- Determination of the kinematic and thermodynamic characteristics inside (toward the eye) and outside of hurricane rainbands, including those that form convective rings.

- Measurement of the characteristics of the middle troposphere and the hurricane boundary layer through utilization of GPS-sonde data.

- Determination of the airflow and the rainband structure in all quadrants of the hurricane.

- Gathering of flight-level and Doppler-derived vertical velocity data in rainbands.

- Documentation of the time evolution and spatial progression of convection within rainbands to determine regions of active and decaying convection.

Mission Description: This experiment requires only one day of flying, but a suitable target with a fairly extensive rainband structure or a concentric eyewall structure is necessary. There are two options included in this experiment: a 'principal band' option and a concentric eyewall option. In addition, a separate rainband module is described. For all aircraft missions, GPS-sondes must be available, and lower fuselage and Doppler radars must be operational. In this study, dual-aircraft options require ~40 total GPS sondes (20 for each aircraft), single aircraft options require 20 GPS sondes, and the rainband module requires 4-8 GPS sondes.

In either option, the two aircraft should stagger their takeoffs. The first aircraft (AC1) will take off ~30-60 min before the second aircraft (AC2) and fly a figure-4 pattern at 10,000 ft (3 km) with ~80 nmi (150 km) legs to document the general reflectivity and wind structure of the storm (**1-2-3-4** in Fig. 19). AC2 will fly ~80 nmi (150 km) legs at ~14,000 ft (4 km) and rendezvous near AC1 at **4** (Fig. 19). GPS-sondes should be dropped inside and outside of the main rainband, and the tail Doppler radar should scan perpendicular to track on radial passes and in F/AST mode on downwind legs. While it is preferred that both aircraft drop sondes and fly legs through the storm, it is essential that the two aircraft arrive at **4** at roughly the same time. To meet this requirement drops can be eliminated and legs can be shortened if necessary.

'Principal band' option: From **4** each aircraft will drop a GPS-sonde and fly downwind. AC1 will remain at 10,000 ft (3 km) and begin its pattern inside the principal rainband (Fig. 20). AC2 will continue to fly at 14,000 ft (4 km) and begin its segment of the pattern outside the rainband. For both aircraft Doppler radar should scan in F/AST mode when flying downwind and perpendicular to the track while crossing the rainband. At **5** the inside aircraft (AC1) will fly across the band to the outside, and AC2 will move to the inside. The aircraft will continue to switch from inside the band to outside the band while dropping sondes as seen in Fig. 20 until the inner aircraft nears the eyewall.

At **7** in Fig. 20, AC2 will continue through the eye (**8**) and rendezvous near AC1 at **9** as both aircraft continue to fly downwind alternating from inside and outside the band as seen in **4-5-6-7**. This pattern is designed to get kinematic and thermodynamic data inside and outside the band. Alternating which aircraft is inside the band assures that neither aircraft proceeds too far ahead of the other while traveling around the storm. It also allows flight level data to be gathered in the band itself. With careful coordination, insuring safety at all times, it may be possible to fly the 'band-crossing' legs to create dual Doppler opportunities in several portions of the rainband.

At. **10**, AC2 (still flying at 14,000 ft - 4 km), will fly a full figure-4 pattern (**10-11-12-13-14** in Fig. 21). AC1 (at 10,000 ft - 3 km) will follow AC2 toward the center and drop sondes on both sides of the rainband and in the storm center. AC2 will not use GPS sondes on its figure-4 until it is clear of AC1 (as seen in Fig. 21). The estimated flight time for this experiment is 5-6 hours, depending on the radius of the rainband from the storm center.

For a single aircraft mission, a figure-4 pattern with ~80 nmi (150 km) legs will be flown between 10,000 ft (3 km) and 14,000 ft (4 km) to identify the overall structure of the storm and to choose a rainband for

RAINBAND STRUCTURE EXPERIMENT

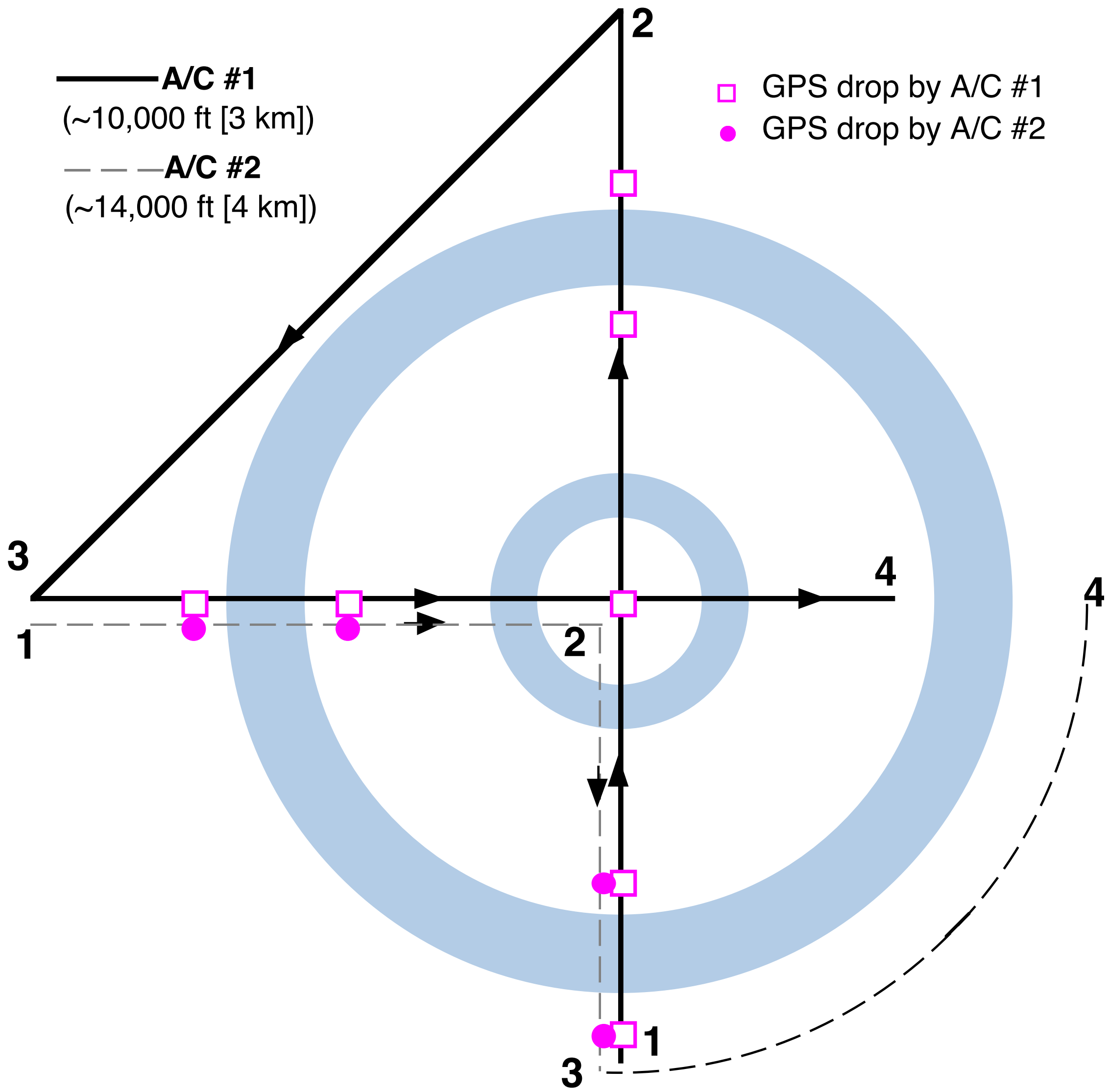


Fig. 19. Beginning Survey Pattern.

• Note 1.	The pattern may be flown along any compass heading.
• Note 2.	**IP** is approximately 80 nmi (150 km) from the storm center.
• Note 3.	Both aircraft should arrive at **4** at the same time. After exiting the eye near **4**, both aircraft begin the downwind rainband portion of experiment.
• Note 4.	Set airborne Doppler radar to continuously scan perpendicular to the track on all radial penetrations, and F/AST on downwind legs.

RAINBAND STRUCTURE EXPERIMENT

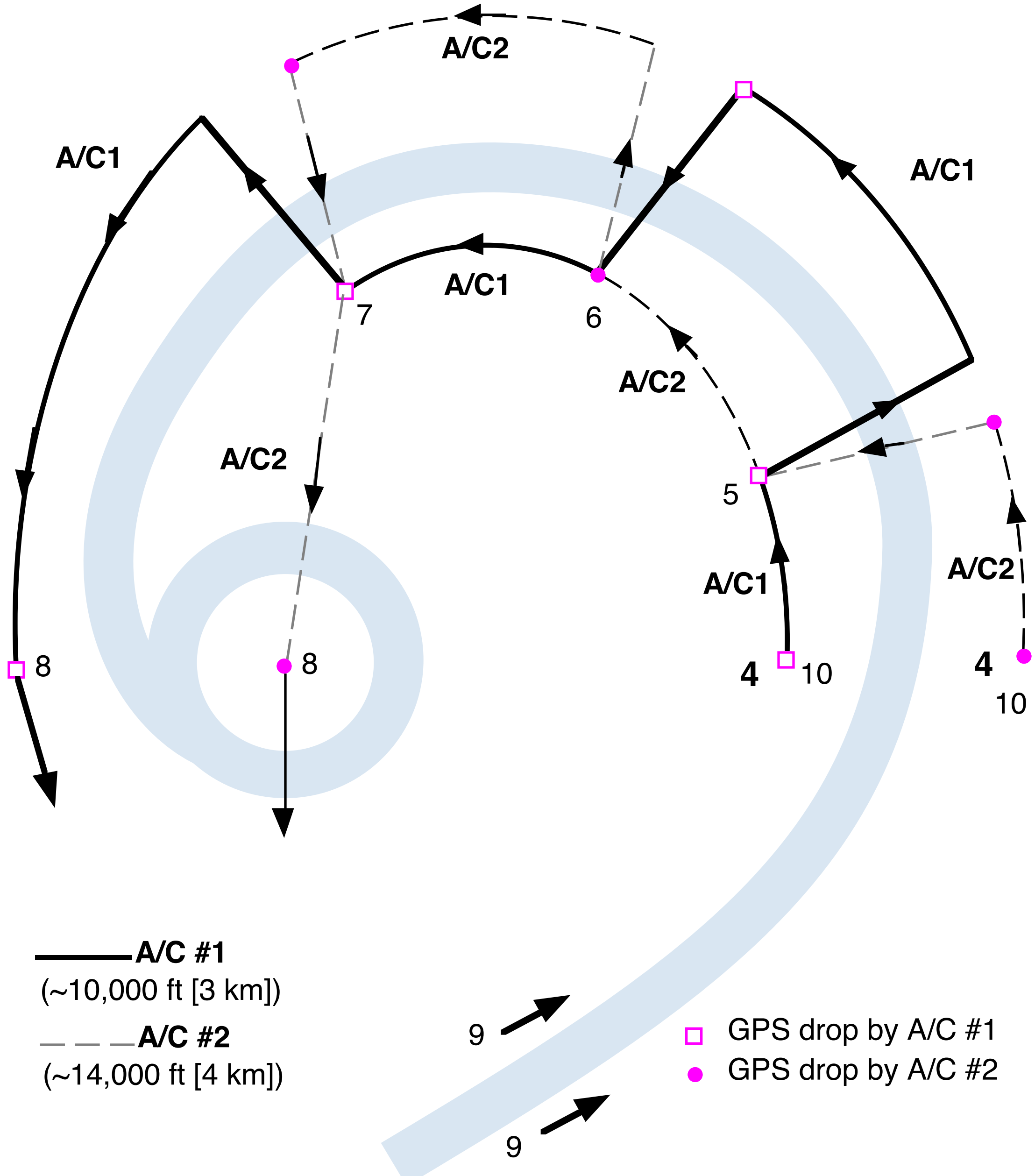


Fig. 20. Principal Band /Concentric Eyewall Option.

• Note 1.	A/C#1 should not fly closer than 33 nmi (60 km) from the storm center. Aircraft separation should not exceed 25 nmi (45 km) on the downwind legs.
• Note 2.	Turn points and drops should be coordinated between aircraft to ensure flight safety.
• Note 3.	Set airborne Doppler radar to F/AST on downwind legs.

RAINBAND STRUCTURE EXPERIMENT

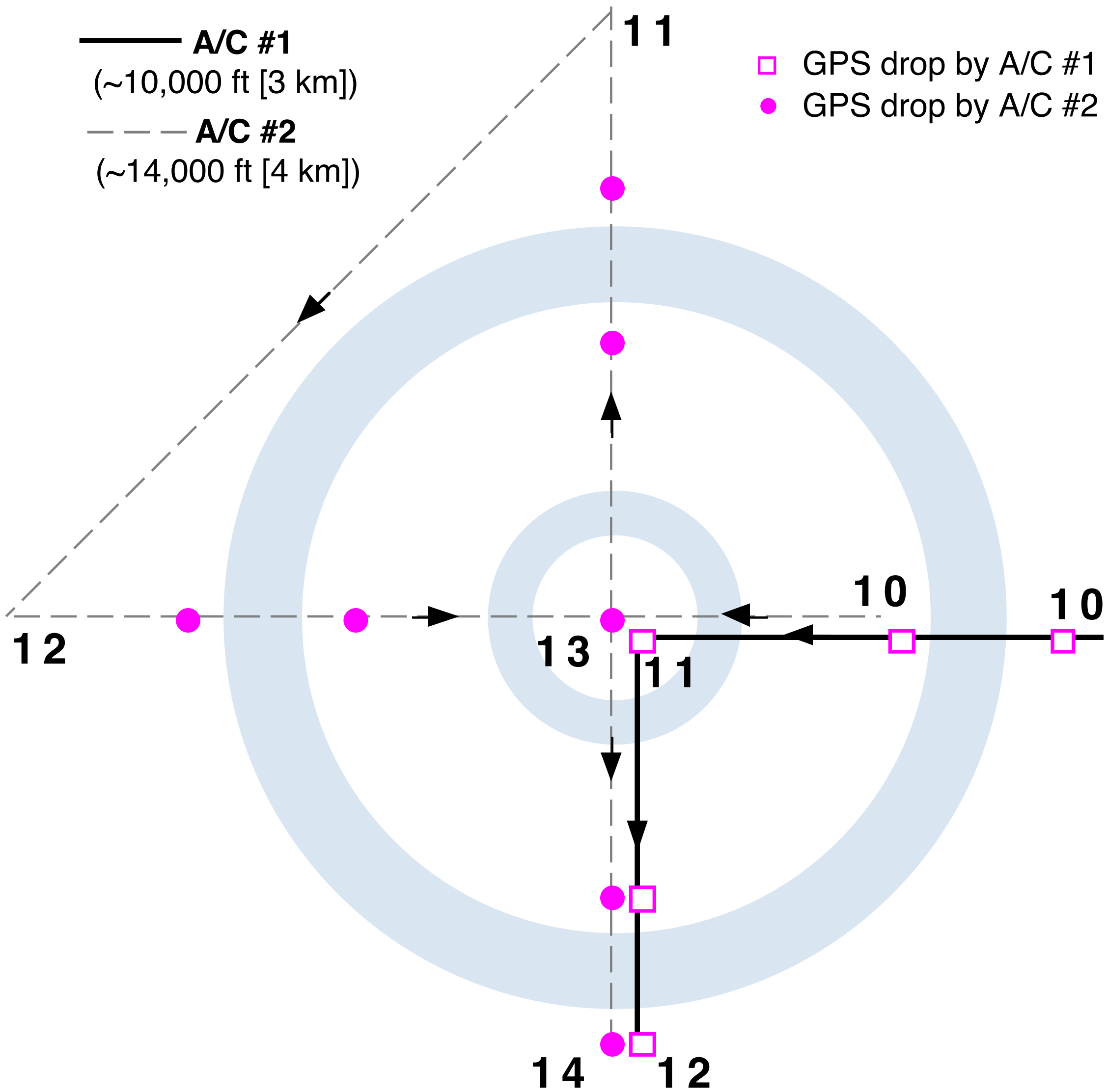


Fig. 21. Final Survey.

• Note 1.	The pattern may be flown along any compass heading.
• Note 2.	**10** is approximately 80 nmi (150 km) from the storm center.
• Note 3.	AC2 will not drop sondes until clear of AC1 on the track to **11**.
• Note 4.	Set airborne Doppler radar to continuously scan perpendicular to the track on all radial penetrations, and F/AST on downwind legs.

investigation. The Doppler radar should scan perpendicular to the flight track when crossing the band and in F/AST mode when flying downwind. A zigzag or sawtooth pattern should be flown across the rainband of interest with GPS-sondes dropped on both sides of the band. At **9**, the aircraft may fly downwind around the storm (flight option 1) or fly upwind to repeat the investigation of the rainband (flight option 2). In either case, GPS-sondes should be dropped along the flight track to gather information on the hurricane environment. A final figure-4 will complete the flight pattern.

[**NOTE**: As the aircraft get closer to the storm center while following a rainband that is spiraling in toward the center, caution must be exercised.]

Concentric Eyewall Option: This option can be executed with dual aircraft or a single aircraft. For dual aircraft, a flight pattern similar to that seen in Figs. 19-21 will be flown with the aircraft alternating which aircraft is on the inside of the band. Since the rainband of interest would exist in all quadrants of the storm, the aircraft will extend the 'principal band' pattern and fly completely around the storm in a pattern similar to that of Fig. 22 (**4-5-6-7**). GPS sondes would be dropped as seen in Figs. 19-21.

For a single aircraft mission, a figure-4 pattern with ~80 nmi (150 km) legs will be flown between 10,000 ft (3 km) and 14,000 ft (4 km) to identify the overall structure of the storm. As in the 'principal band' option, the Doppler radar should scan perpendicular to the flight track when crossing the band and in F/AST mode when flying downwind. A zigzag or sawtooth pattern should be flown across the rainband of interest with GPS-sondes dropped on both sides of the band. A final figure-4 will complete the flight pattern.

- **Rainband module**: The single aircraft rainband module has been designed to be flown with other experiments in "rainbands of opportunity" and last 30-60 min (Fig. 22). The goal of the module is to gather data inside, outside, and across several rainbands of several storms over several seasons. While individual data sets will increase our understanding of the structure of rainbands, the primary objective here is to develop a database of rainband observations for future comprehensive study.

RAINBAND STRUCTURE EXPERIMENT

Single Aircraft Option

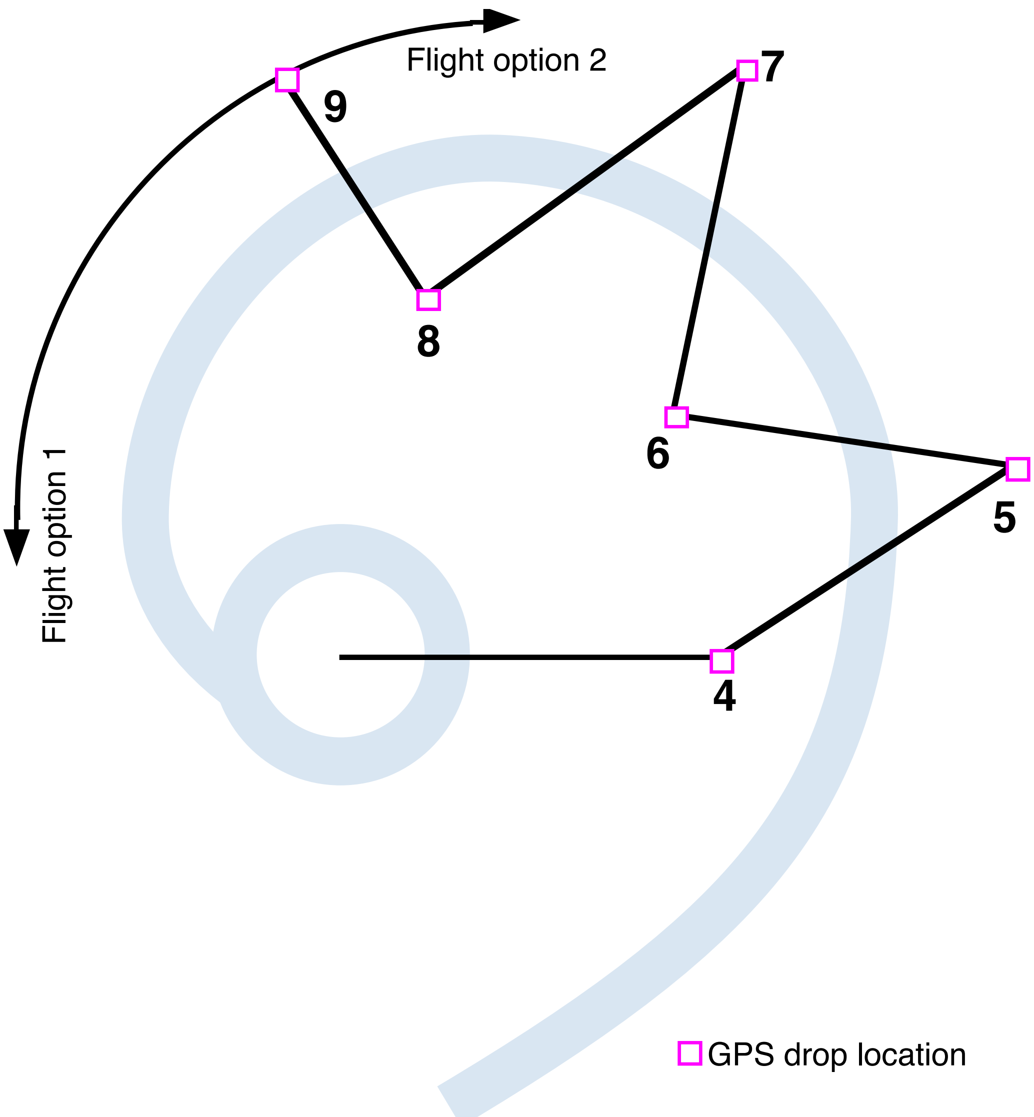


Fig. 22. Rainband Module—Single Aircraft Option.

• Note 1.	Fly zig-zag legs **4-9** at 10,000-14,000 ft (3-4 km) altitude, below the melting level. Each leg is approximately 25 nmi (45km) long. Outside turns of 270°-300° are at the end of each zig-zag leg. GPS-sondes will be dropped on both sides of the band.
• Note 2.	At **9** fly downwind around the eyewall (option 1), or upwind along rainband (option 2) to a point near the beginning of the zig-zag legs.
• Note 3.	Repeat pattern in different parts of the storm as time permits.
• Note 4.	Set airborne Doppler radar to continuously scan perpendicular to the track on all radial penetrations or zig-zag legs, and F/AST on upwind or downwind legs.

16. Electrification of Tropical Cyclone Convection Experiment

Program Significance: Cloud electrification has been a topic of great scientific interest for many years, but the lack of suitable instruments for measuring electric fields and particle charges in clouds has hindered research. From anecdotal evidence, meteorologists have considered that hurricanes usually have little electrical activity. However, the introduction of wide-area lightning detection systems along the U.S. coast has resulted in several case studies of lightning from tropical storms and hurricanes. These data show that a larger proportion of TCs produce cloud-to-ground (CG) lightning than was previously known.

Neither the microphysical nor electrical structure of TC clouds that exhibit lightning is known. Laboratory experiments have shown that more charge is separated when ice crystals collide with a rimed target in the presence of supercooled water than is separated without supercooled water. They also showed that the sign of the charge transferred reversed at about -20°C. Other laboratory experiments showed that the growing conditions encountered by the ice particles determined the sign of the charge that was transferred between them during collisions. Observations in continental thunderstorms support this hypothesis and suggest that charge separation occurs most rapidly on the boundary between the main updraft and the downdraft near -15°C. More recent observations showed that sublimating graupel acquire negative charge and graupel undergoing deposition acquire positive charge. As these processes depend critically upon the graupel temperature and cloud liquid water content, it is highly desirable to obtain suitable measurements in natural clouds.

In mature hurricanes, updraft velocities are usually low. In addition, graupel and ice particles are plentiful, but supercooled cloud water is rare in hurricanes at temperatures as warm as -5°C. Studies of two mature Atlantic hurricanes have shown that the little supercooled water present in the strongest eyewall updrafts was immediately adjacent to areas that contained high concentrations of small ice particles. When one considers the lack of supercooled water in mature hurricanes, it is not surprising that mature hurricanes are not always electrified. However, the National Lightning Detection Network (NLDN) detected lightning in several hurricanes and tropical storms as they approached land.

A recent investigation noted that there appeared to be a relationship between the occurrence of CG lightning in the eyewall and a subsequent intensification of the hurricane. A similar relationship was proposed by studies of lightning observations in two developing TCs. In each case, lightning was qualitatively associated with exceptionally strong convection, which occurred when the storms were rapidly intensifying. In addition, recent observational studies of CG lightning in TCs using data from the NLDN showed that CG lightning is most prevalent in the outer convective rainbands of hurricanes with little CG lightning near the eyewall. An apparent paradox is thus created as research shows that vertical velocities in rainbands are weaker than those in the eyewall. It is important to note, however, that rainbands >54 nmi (100 km) outside of the eyewall remain virtually unsampled.

Although these observational studies analyzed lightning in TCs, none of them included cloud microphysics or vertical velocity measurements. The inclusion of these data are critical to better understanding the relationship between cloud physics, vertical velocity, and CG lightning. Combining these three data sets will allow further investigation into the possible implications of CG lightning to intensity changes in TCs.

In view of these observations, we believe that supercooled water and charge separation occasionally occur in the strong convection in TCs. Recent additions to the WP-3D instrumentation that make electrification studies possible are four rotating vane field mills that measure **E** (the vector electric field) and an induction ring that measures the charge on individual particles. The development and testing of these instruments will continue through 1997.

Objectives: The objectives of this experiment are to study the temporal evolution of the electric field and microphysical and kinematic properties in TCs. The specific goals are:

- Measure the sign and magnitude of the vector electric field near the eyewall and in an outer convective rainband.

- Document the three dimensional wind field in electrified clouds, including the vertical winds estimated from the Doppler radar.

- Determine the polarity and magnitude of the charge on ice precipitation at several temperature levels above the melting level.

- Estimate the transport of electrical charge in the storm.

- Record the types and concentrations of all particle types observed in the electrically active portions of the storm.

Mission Description: This experiment documents the microphysical characteristics of electrically active convection using a single aircraft. The new Particle Measuring System (PMS) 2-D greyscale probes, the new PMS FSSP-100, and the University of Nevada, Desert Research Institute (DRI) field mills are essential. The DRI induction ring, the tail Doppler radar, and the cloud liquid water probes (Johnson-Williams [JW] and King) are highly desirable. Horizontal and vertical wind field measurements will be obtained from the Doppler radar. The aircraft should execute a standard true airspeed (TAS) calibration in clear air prior to entering the storm if conditions permit.

This study requires that one aircraft be equipped with the DRI electric field instruments in addition to the standard instrumentation. The PMS probes must be the best available, and the radars must be fully operational. The experiment is composed of three options. In all options, it is desirable to have 4 to 6 GPS-sondes to obtain soundings outside the convection in the inflow near the areas of interest. The aircraft should loiter in the eye or any other suitable area when it is necessary to service equipment.

Eyewall option: To execute this option, the aircraft will fly radial legs out and back at constant radar altitude upon a reciprocal track through the eyewall at successively higher altitudes starting at the stratiform area melting level (~16,000 ft [4.8 km]) until the maximum operational altitude is reached. An dropwindsonde should be dropped outside the eyewall on the highest altitude leg to obtain a vertical sounding. Each successive radial pass (out and back) shall be 1,500 ft (500 m) higher than the previous one. Climbs and descents should occur in clear areas outside the eyewall (**2** in Fig. 23), and leg lengths shall be altered as necessary to achieve this. This out and back pattern (**1-2-1** in Fig. 23) should be repeated until the aircraft reaches its maximum attainable altitude. The Doppler radar should be operated in a 360° scan mode during the radial passes. Upon completion of the radial legs, an equilateral triangle Doppler pattern will be executed, starting from inside the eye. The starting azimuth (Fig. 23) will be 60° upstream from the upstream edge of the strongest radar reflectivity feature in the eyewall or innermost convection. The legs should be ~43 nmi (80 km) long, with the inbound leg connected to the outbound leg by a downwind leg. The inbound leg should penetrate the convection at the downstream edge of the strong reflectivity area previously identified. Each triangle will require 10-20 min to complete, depending upon the leg length.

Rainband option: If a convective outer rainband is available >80 nmi (150 km) from the eye, it should first be surveyed for evidence of electric fields. The survey consists of flying along the band until the field mills register a space charge or the Doppler radar reveals the presence of vigorous convection. When an interesting area is located, the aircraft should either seek a clear area and climb to maximum altitude or descend to the 0°C (~16,000 ft [4.8 km]) altitude, whichever is closer, and start making passes downwind (Fig. 24) through the middle of the band the feature. Each downwind pass (Fig. 24, **1-2**) should maintain a track along the axis of the band and be about 50 nmi (93 km) long and 1,500 ft (500 m) higher (lower) than the previous one. During this portion of the pattern, the Doppler radar should make 360° scans normal to the aircraft track. After the downwind pass is completed, the aircraft should exit the band on the outer side, climb (descend), and return (Fig. 24, **3-4**) upwind to the start of the band. The

ELECTRIFICATION OF TROPICAL CYCLONE CONVECTION EXPERIMENT

Eyewall Module

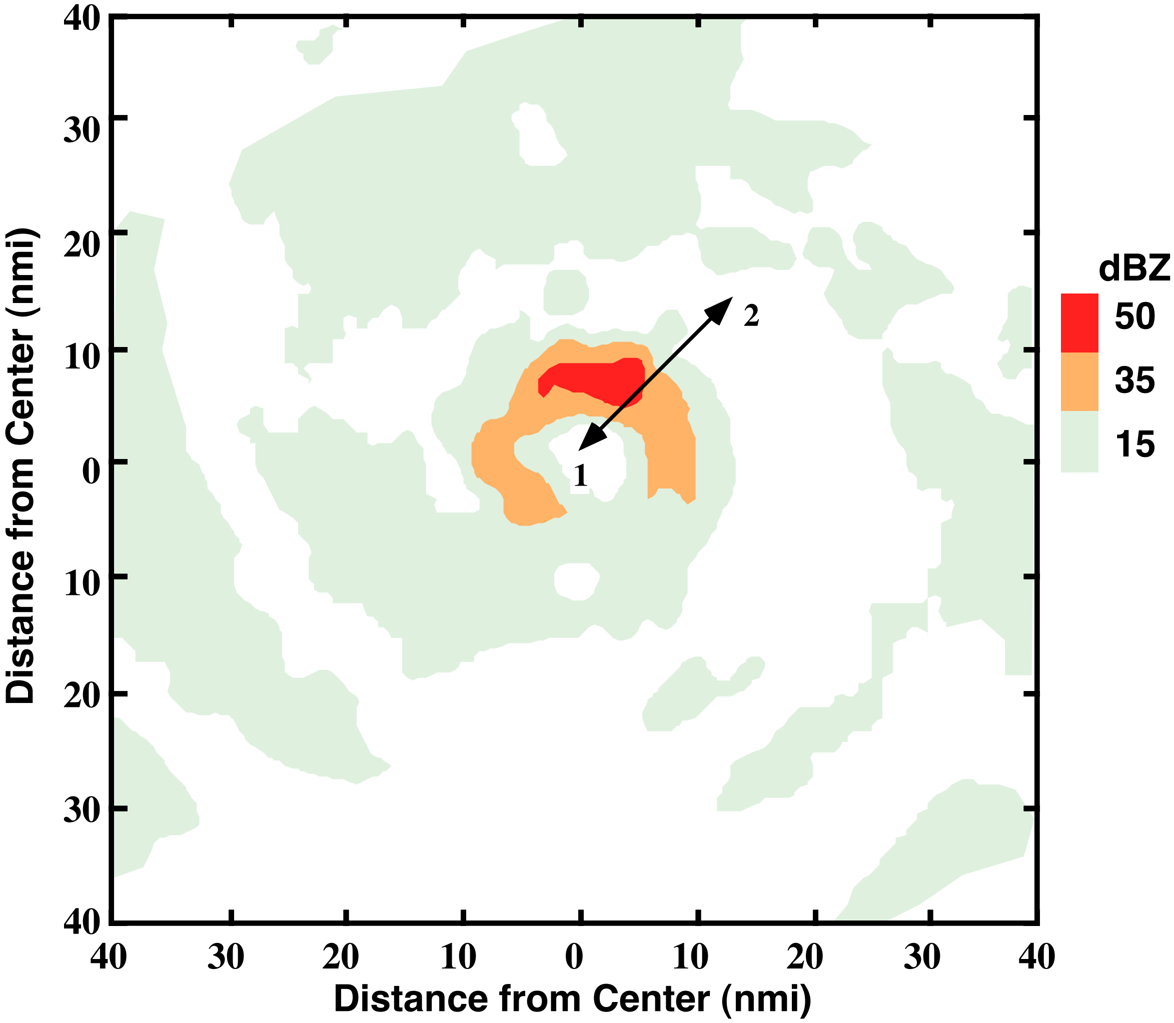


Fig. 23. Convection/Eyewall module flight pattern.

• Note 1.	True airspeed calibration is required.
• Note 2.	The pattern may be entered along any compass heading.
• Note 3.	Radial penetrations are separated by 1,500 ft (500 m) altitude and occur along track **1-2-1**.
• Note 4.	Set airborne Doppler radar to continuously scan perpendicular to the track on radial penetrations.

ELECTRIFICATION OF TROPICAL CYCLONE CONVECTION EXPERIMENT

Rainband Module

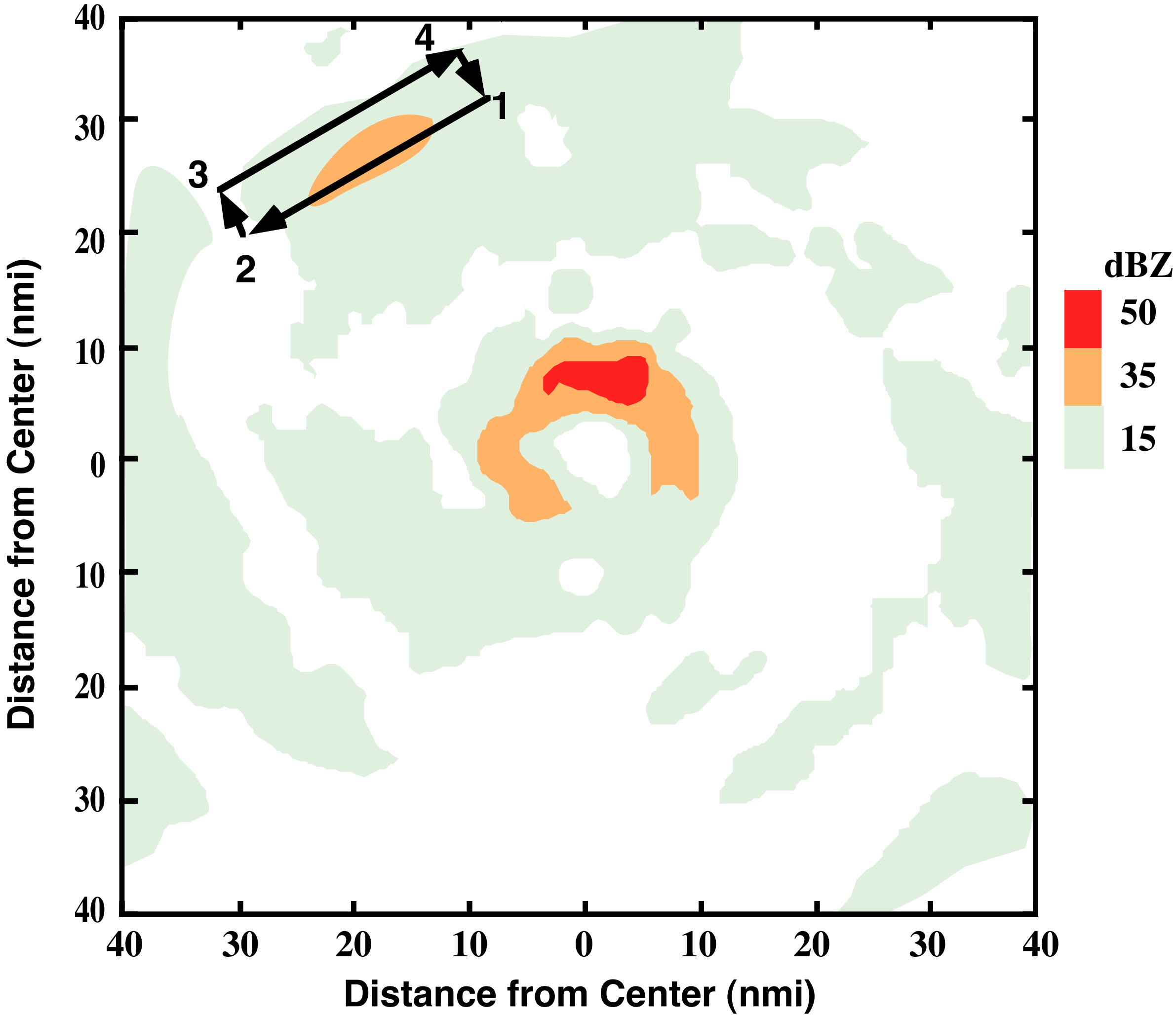


Fig. 24. Convection/Rainband module flight pattern.

- Note 1. True airspeed calibration is required.
- Note 2. The pattern may be flown along any compass heading.
- Note 3. Rainband passes **1-2** are separated by 1500 ft (500 m) altitude. Climbs occur along **3-4** away from the convection.
- Note 4. Set airborne Doppler radar to continuously scan perpendicular to the track from **1-2**, and F/AST on all other legs.

Doppler data will be obtained on the upwind pass using the F/AST method. This pattern will require about 20 min to execute. Pass length may be altered as circumstances dictate. Repeat this pattern until the maximum altitude is reached, or seek a new area as desired. As an alternate, a zig-zag path downwind through the convective band may be flown if necessary for flight safety.

(**Note**: If the feature of interest is not translating, radial legs should be flown on a constant track instead of a constant heading. The length of the radial legs depends upon the diameter of the eye and the width of the rainband, respectively. Turns should be initiated into the wind.)

Landfalling storm option: The purpose of this option is to investigate the relationship between cloud physics, vertical velocity, and the occurrence and location of CG lightning. Outer convective rainbands are of primary interest since they are the most likely features to be electrified. Vertically pointing Doppler rays are used to estimate vertical air motions during passes through active convection in both tropical storms and hurricanes. Along with the vertical velocities, coincident microphysics and electric field measurements are made at heights above the melting level. Three-dimensional wind fields of the convective areas can be constructed from a Pseudo-dual Doppler technique and from the F/AST Doppler data. CG lightning data are available within 325 nmi (600 km) range of the NLDN (Fig. 26). Together, these data sources and techniques should lead to a better understanding of the characteristics of the convective processes that lead to lightning in hurricanes and, possibly, to intensity changes of the storms.

For this option, the aircraft will initially fly a survey figure-4 pattern (Fig 25a) at ~18,000 ft (5.5 km) altitude. The figure-4 pattern would be completed in 1.5-2.0 h with radial legs 80 nmi (150 km) in length. The second part of this option (Fig. 25b) concentrates on rainbands that are located within the useful range of the NLDN. Upon exiting the eye at **4**, the aircraft should climb as high as possible on the way to the rainband of interest (**5**). A sawtooth pattern is flown downwind (Doppler operating in standard mode) with repeated crossings of the rainband to **6**. We prefer to fly directly down the band as noted in Fig. 24, but for reasons of safety, a sawtooth pattern may be flown. An upwind leg, flown outside of the band, is performed with the tail radar operating in the F/AST mode. The sawtooth pattern across the band is repeated with an exit toward the eye at **7**. After entering the eye, the aircraft turns toward the second rainband at **8**. The sawtooth crossings and the F/AST downwind leg are repeated as in the first rainband. A final center fix is made (time permitting) before returning to base from **10**. About one hour should be spent in each of the rainbands. If only one rainband is present within the useful range of the NLDN, a second study of the same band can be performed after a circuit through the storm center.

ELECTRIFICATION OF TROPICAL CYCLONE CONVECTION EXPERIMENT

Survey Module

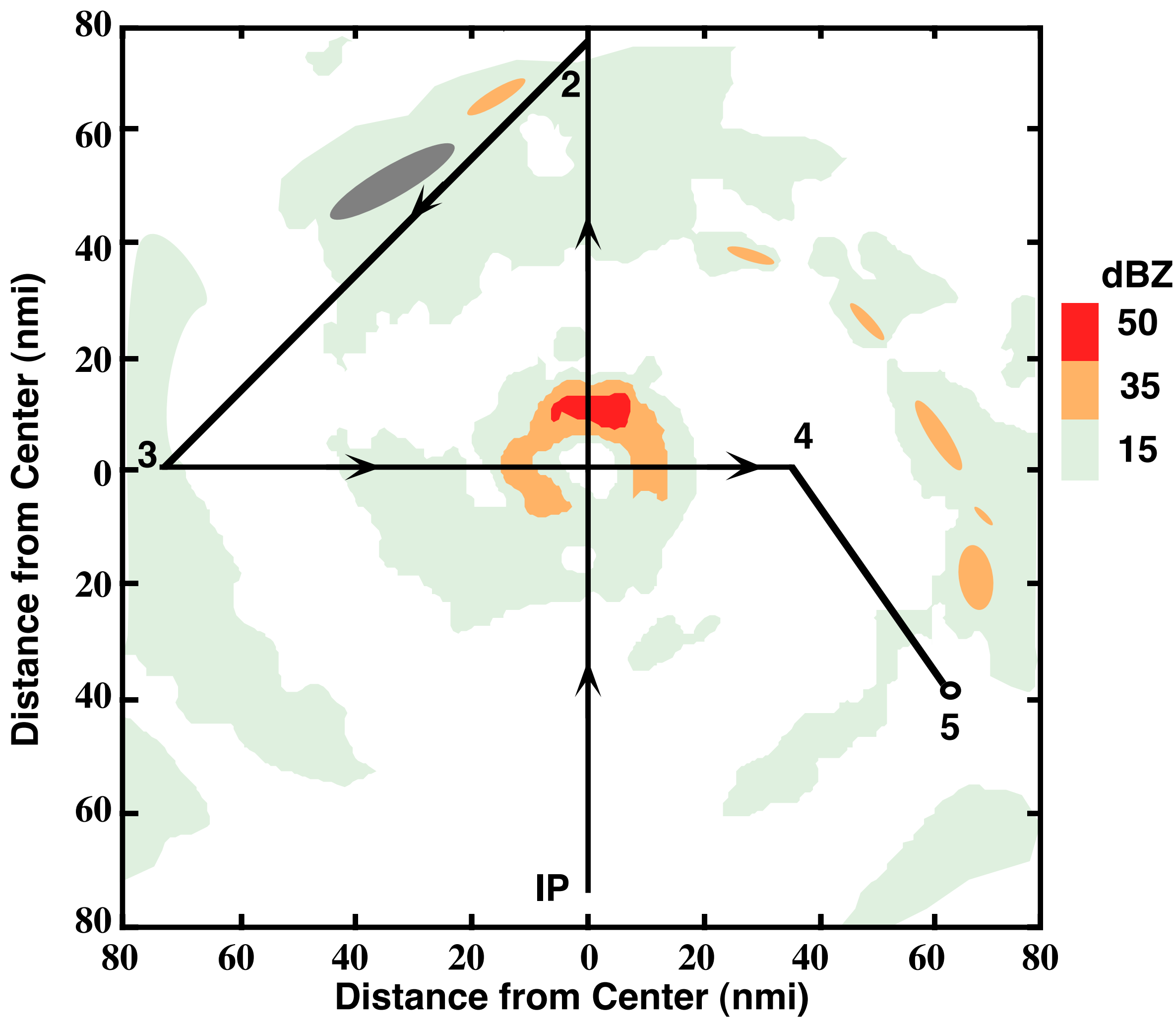


Fig. 25. (a) Convection/Survey module flight pattern.

• Note 1.	The pattern may be flown along any compass heading.
• Note 2.	Fly **IP-2-3-4** at 18,000 ft (5.5 km). **IP** is approximately 80 nmi (150 km) from the storm center.
• Note 3.	After exiting the eye near **4**, select upwind portion of a rainband for rainband portion of experiment.
• Note 4.	Set airborne Doppler radar to continuously scan perpendicular to the track on all radial penetrations, and F/AST on downwind legs.

ELECTRIFICATION OF TROPICAL CYCLONE CONVECTION EXPERIMENT

Rainband Module

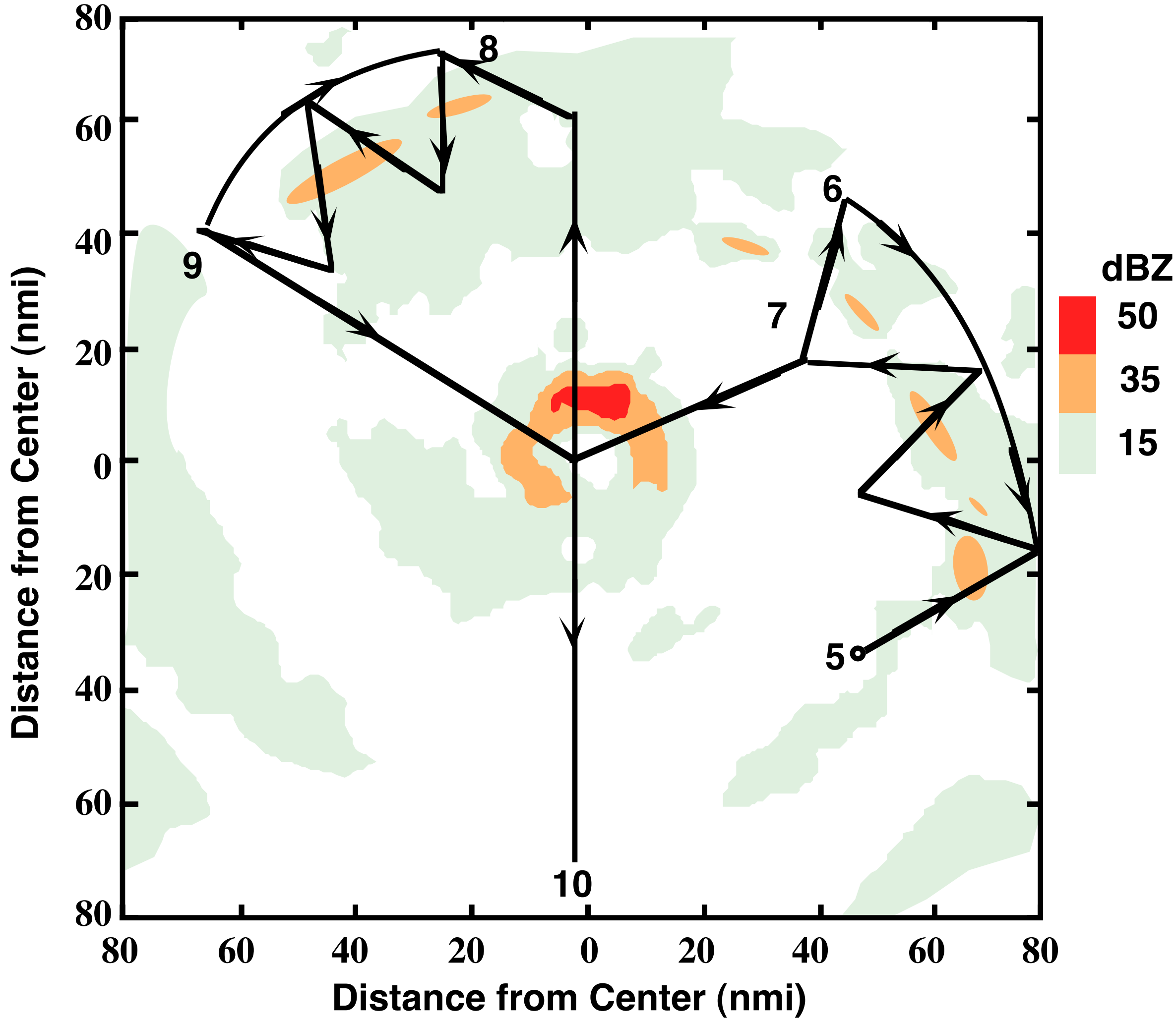


Fig. 25. (b) Convection/Survey rainband module flight pattern.

• Note 1.	Fly zig-zag legs **5-6** and **8-9** at highest possible altitude. Each leg is approximately 25 nmi (45km) long. Outside turns of 270°-300° are at the end of each zig-zag leg.
• Note 2.	At **6** and **9** fly upwind leg along rainband at highest possible altitude to a point near the beginning of the zig-zag legs.
• Note 3.	Repeat pattern in different parts of the storm as time permits.
• Note 4.	Set airborne Doppler radar to continuously scan perpendicular to the track on all radial penetrations or zig-zag legs, and F/AST on upwind legs along the rainband.

ELECTRIFICATION OF TROPICAL CYCLONE CONVECTION EXPERIMENT

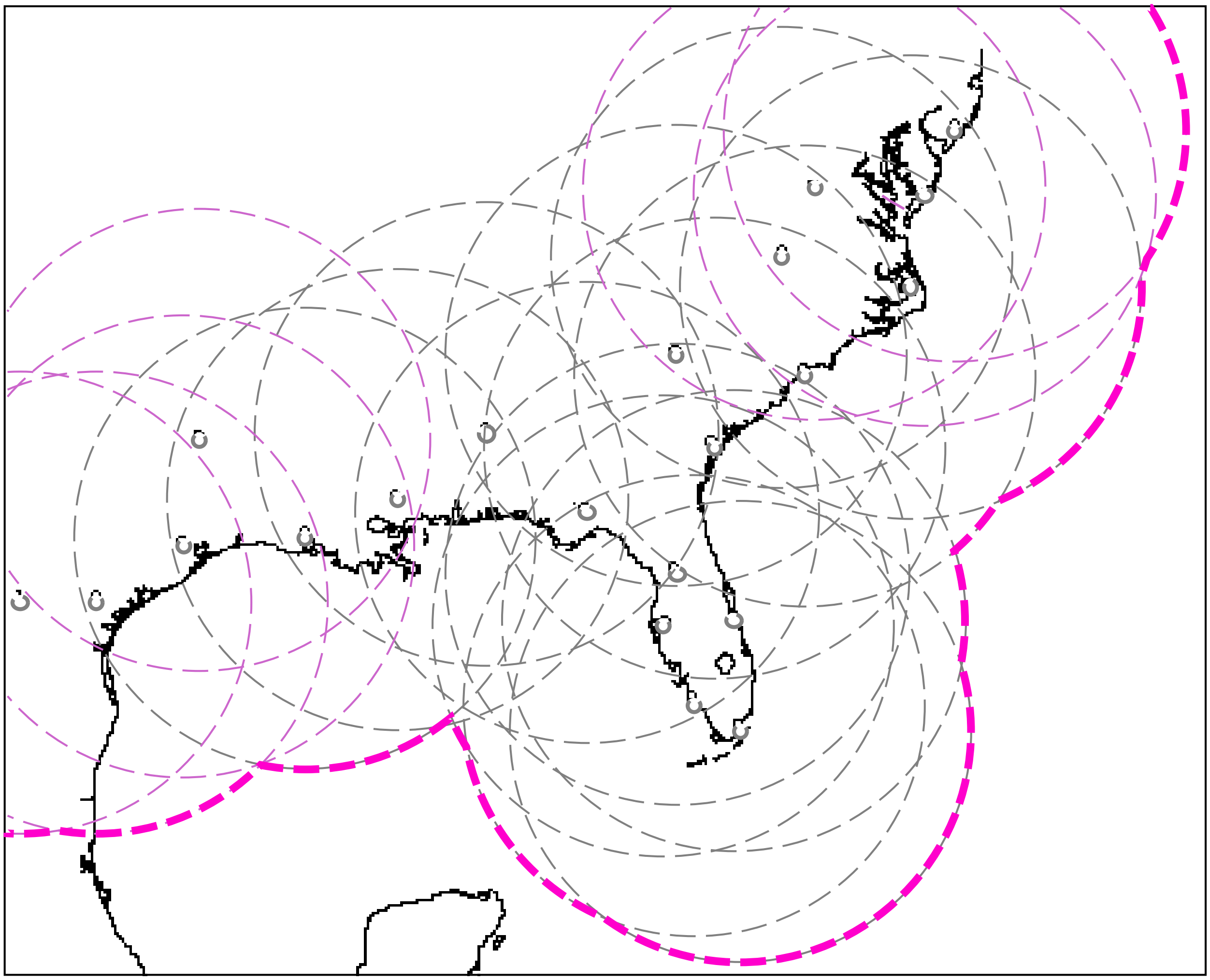


Fig. 26. **Coastal lightning direction finders (DFs) of the NLDN. Range rings are at 325 nmi (600 km) radius from each site. The 'O' symbol denotes the approximate DF location. DF positions were provided by Texas A&M University.**

17. Eyewall Vertical Motion Structure Experiment

Program significance: Deep convection occurs in the hurricane eyewall and is the primary region for organized vertical motions. Updrafts typically cover a large portion of the eyewall's area and may extend several kilometers in the vertical. This deep, organized convection in the hurricane eyewall is necessary to maintain or to increase the storm's intensity. Knowledge of the three-dimensional structure of vertical motions in the eyewall are crucial for understanding the internal processes that govern intensification. The remote-sensing capability of the Doppler radar on the WP-3D aircraft, combined with the accuracy of Global Positioning Satellite (GPS) navigation, allows for the study of eyewall vertical winds in greater detail than was formerly available.

Previously, the study of vertical motions in hurricanes was limited to data collected by research aircraft at flight levels in the lower troposphere. More recently, utilization of airborne Doppler data from vertically pointing radar rays (vertical incidence) allowed researchers to estimate vertical motions throughout the depth of the troposphere. The Doppler data were available in vertical planes along the aircraft track, providing a two-dimensional (radius-height) analysis of hurricane vertical wind structure. These analysis confirmed the results of the flight-level study in that the eyewall contained the strongest and largest updrafts and which were capable of transporting air with large amounts of moist static energy from the boundary layer to the upper troposphere. These vertical transports of mass are necessary for the maintenance and intensification of the hurricane. Updrafts in the eyewall, some of which appeared to extend throughout the depth of the eyewall, exhibited a pronounced radially-outward slope with height.

While the persistent and organized two-dimensional spatial structure of eyewall updrafts was revealed in the Doppler studies, questions remain concerning the asymmetric distribution and structure of eyewall vertical motions. Eyewall updrafts not only slope radially outward with height, but because of the strong horizontal winds and large vertical shear of the horizontal wind, updrafts undoubtedly have a large slope in the azimuthal plane as well. Pseudo-dual Doppler analysis suggested this type of structure but because of limitations in both time and spatial resolutions, the actual structure remains uncertain. Additionally, large variations in the magnitude and size of eyewall vertical motions have been observed among different hurricanes and appear to be related to intensity and intensity changes. Furthermore, large asymmetries in eyewall vertical motions are related to the precipitation structure and may be a result of the environmental shear through the eyewall.

With the advent of GPS navigation, both dual-Doppler analysis and vertical-incidence data from coordinated, parallel flight tracks of both WP-3D aircraft can be used to study, in detail, the three-dimensional structure of eyewall vertical motions. The GPS navigation provides accurate positioning of the aircraft, relative to the storm center, resulting in smaller errors in the total wind field, including vertical velocity estimates. Data collected simultaneously from both aircraft in two adjacent radius-height profiles through the eyewall can be used to infer the azimuthal continuity of the largest up- and downdrafts. The dual-Doppler analysis may confirm the highly organized nature of these drafts. The data collected from this experiment will be used to expand knowledge of the relation between vertical motion structure and intensity change and to provide a basis for use in numerical modeling efforts of hurricane eyewall processes that lead to intensification or weakening.

Objectives:

- To map the three-dimensional spatial structure of the hurricane eyewall up- and downdrafts from dual-vertical incidence data and to use dual-Doppler analysis to relate the vertical motion structure to the effects of environmental shear through the eyewall.

- To investigate the relation between vertical motion structure and asymmetries in the hurricane eyewall to changes in the intensity of the storm.

- To refine the conceptual model of the three-dimensional reflectivity and vertical motion structure of the eyewall for use as ground truth in numerical models of the tropical cyclone.

Mission Description: The Eyewall Vertical Motion Structure Experiment (EVMSE) will use both NOAA P-3 aircraft flying highly coordinated flight patterns to map the three-dimensional structure of eyewall vertical motions. The primary requirement is for the target storm to have an eyewall (or a developing one) with substantial areas of deep convection. Both aircraft must have fully operational tail radar systems and at least one aircraft must have a working lower fuselage radar. Recording of cloud physics data is desired but not necessary. The aircraft will fly at two altitudes, one at either 6,000 ft (1.8 km) or 12,000 ft (3.6 km) and the other at 8,000 ft (2.4 km) or 14,000 ft (4.2 km). The lower of the two aircraft should have up to 12 GPS dropsondes available for deployment in the eye, eyewall, and outside of the eyewall. The first and last portions of the mission includes coordinated "figure-4" patterns (Fig. 27a) with leg lengths nominally set at 75 nmi (140 km). The length may vary depending on the size of the eye. After completing the initial "figure 4", the aircraft will rendezvous in a relatively clear area outside of the eyewall to coordinate an inbound leg into the eye (Fig. 27b). The aircraft should fly at the same ground speed so as to be parallel to each other along the radial leg. The horizontal spacing between aircraft can vary from 1,500 ft (0.5 km) to 6,500 ft (2.0 km) and the vertical separation can be 2,000 ft (600 m) or greater, depending on safety considerations. The dual vertical-incidence module (Fig. 27a) consists of coordinated radial legs into and out of the eye with downwind legs flown outside of the eyewall between the outbound and inbound legs. The radial legs will typically be 40-60 nmi (70-110 km) long, depending on the eye size. Coordination between aircraft should be done in clear air in the eye and outside of the eyewall at the end of the downwind legs. If the eye diameter is too small to maneuver the aircraft, straight legs through the eye and eyewall may be used. The series of radial legs should be repeated so as to maximize the areal coverage of the eyewall, but to allow time for a coordinated "figure-4" pattern at the end of the flight.

EYEWALL VERTICAL MOTION STRUCTURE EXPERIMENT

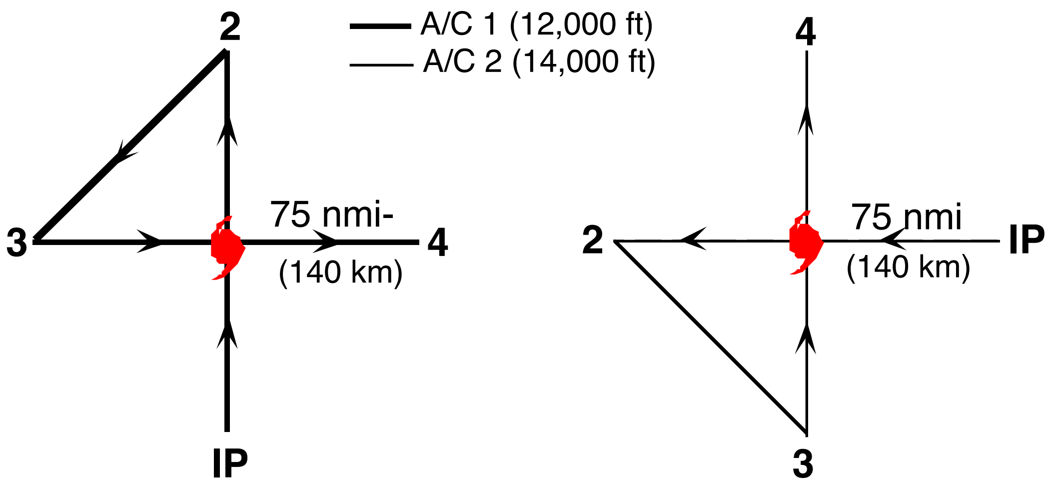


Fig. 27. (a) Coordinated dual-Doppler pattern

• Note 1.	Dual-Doppler pattern flown at beginning and end of mission.

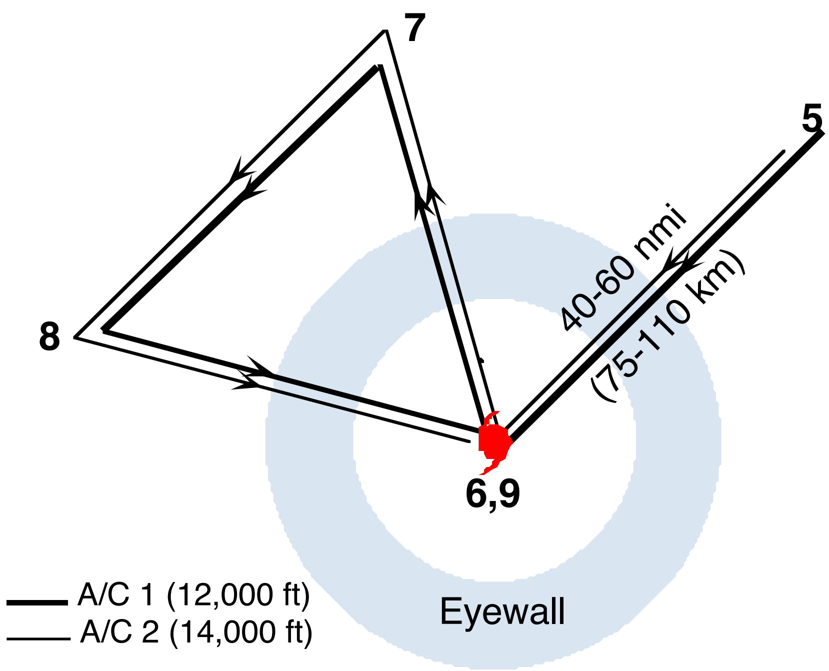


Fig. 27. (b) Eyewall dual-vertical incidence module

• Note 1.	A/C coordinate at **5** and fly parallel at the same ground speed with horizontal spacing of ~1 nmi (2 km).
• Note 2.	Coordination points in relatively clear air at points **5,6,8,** and **9**.
• Note 3.	Straight legs through the eye and eyewall may be used if the eye size is too small to maneuver the aircraft.
• Note 4.	Repeat pattern (**6-7-8-9**), rotating 60° downwind allowing time for final figure-4.

18. Clouds and Climate

Program Significance: It has become widely recognized that the physics of clouds and precipitation must be considered in any realistic study of climate change. Clouds and water vapor play a pivotal role in the Earth's heat and radiation budgets. They control the amount of solar energy absorbed by the climate system as well as the infrared radiation emitted to space, and they strongly influence the redistribution of heat throughout the climate system, particularly in the tropics. Tropical clouds and cloud systems, because they lie in the zone of maximum solar input into the atmospheric system, have an important, and probably direct climatic effect. Together with the release of latent heat, the radiative heating of layered clouds in the upper tropical troposphere is a significant source of energy for driving the global circulation. A wide spectrum of tropical cloud types and sizes are important from a climate viewpoint. In some instances, the very small scale microphysical characteristics of the clouds, and interactions with the cloud dynamics, are important on the climate scale.

Small precipitating tropical cumuli, even though their fraction of active convective updrafts may be rather small at any given instant, have an aggregate fraction of total cloud cover, including decaying clouds that is in the range of 20-30%. Hence, they have a direct effect on the radiative transfer in the tropics. In addition, they have an effect on the turbulent mixing in the upper ocean through changes in radiative heating of the sea surface, and through precipitation into the sea surface. The behavior of these small clouds is linked to the ocean, and the ocean to the behavior of these clouds. As sea surface temperature influences the atmosphere on various time and space scales, clouds and upper ocean dynamics are inextricably linked.

This study is complimentary to our continuing work on studies of the dynamics and microphysics of hurricane convection. The oceanic cumulus provides a simple, easily observed convective entity that has more similarities to hurricane convective clouds than differences. One advantage is that the precise stage of an oceanic cumulus in its life cycle is usually definable. Thus answering questions about this simpler entity will complement the hurricane observation program, and greatly aid in the interpretation of more complex data sets from large international field programs. We can exploit our extensive observational capability in the natural convective laboratory at our doorstep (Florida Bay, Bahamas, and the Caribbean Sea) for a relatively meager investment of resources. The result will be an increased understanding of principles that are applicable to convection in general.

The detailed microphysical measurements will also be useful to studies of the characteristics of precipitation in the tropics. The precipitation characteristics derived from this proposed experiment will provide a data base for statistical rainfall studies underway in support of the Florida Bay Restoration Act, the Climate and Global Change Initiative, TOGA COARE, and TRMM. These studies call for rainfall estimates to be made in different precipitation regimes around the world. This data set will provide data on isolated topical convective clouds.

Objectives: The experiment will document the kinematics and microphysics of a representative sample of convection, with the initial emphasis being on small precipitating convective cells. We are particularly interested in these clouds` life cycle evolving from first condensation to a precipitating stage (glaciated or not). The specific scientific objectives of this experiment include:

- Building a data base, or census, of small precipitating cumulus; e.g., dimensions (top height, diameter, and depth) and precipitation characteristics that has potential uses in several facets of climatic analysis.

- Documenting the thermodynamic and wind environment of the clouds. Mapping the three dimensional flow field within an active convective feature, and computing the hydrometeor trajectories into the region surrounding the storm using the airborne Doppler radar.

- Collecting rainfall statistics of oceanic convection for use in statistical rainfall studies.

- Testing the capability of determining the hydrometeor distributions from the reflectivity and Doppler mean velocity data at, or near, vertical incidence.

- Documenting the initial electrification and the evolution of the electric field within a sample of clouds.

- Documenting the characteristics of significant convective updrafts - water mass flux, the evolution of ice particles in the updrafts and the conversion rates to ice.

- Studying the relationship between initial and subsequent precipitation formation and the interaction between precipitation loading and the dynamics of the convective cell.

- Studying the interactions between warm cloud and ice microphysics at different stages of cloud development. Emphasis will be placed on the warm rain development versus rain from glaciation.

Mission Description: The experiment calls for a basic one-aircraft cloud structure and evolution sampling module (Fig. 28). This simple module could be executed during dedicated flights over Florida Bay or the Keys, or on targets of opportunity during deployments. Sampling during dedicated flights will emphasize combinations of remote sensing and cloud penetrations, while remote sensing will be used during deployments.

The basic cloud sampling module utilizes one aircraft, equipped with the airborne Doppler radar and microphysics instrumentation, to investigate maritime convective clouds. Desired candidates for study should be convective clouds that can be followed through nearly their entire life cycle. The flight patterns of the basic cloud sampling module are shown in Fig. 28, and are relatively straightforward. The aircraft will make rapid repeated penetrations of the cloud, to sample the microphysical and electric field development at a constant distance below the cloud top. The attempt will be to document the microphysics and electric field development near cloud top from first condensation through a mature cloud stage. At each pass through the cloud, vertical incidence Doppler data will be collected to document the evolution of the vertical velocity field as the cloud matures. These patterns, or penetrations, will be oriented based upon the environmental wind shear vector. The aircraft will release a GPS-sonde or perform an aircraft sounding in the environment of each cloud sampled (in the clear, upwind of the cloud). The aircraft will also attempt to sample the boundary layer air flow, rainfall characteristics, the warm cloud microphysics, and photo-document the cloud behavior.

CLOUDS AND CLIMATE EXPERIMENT

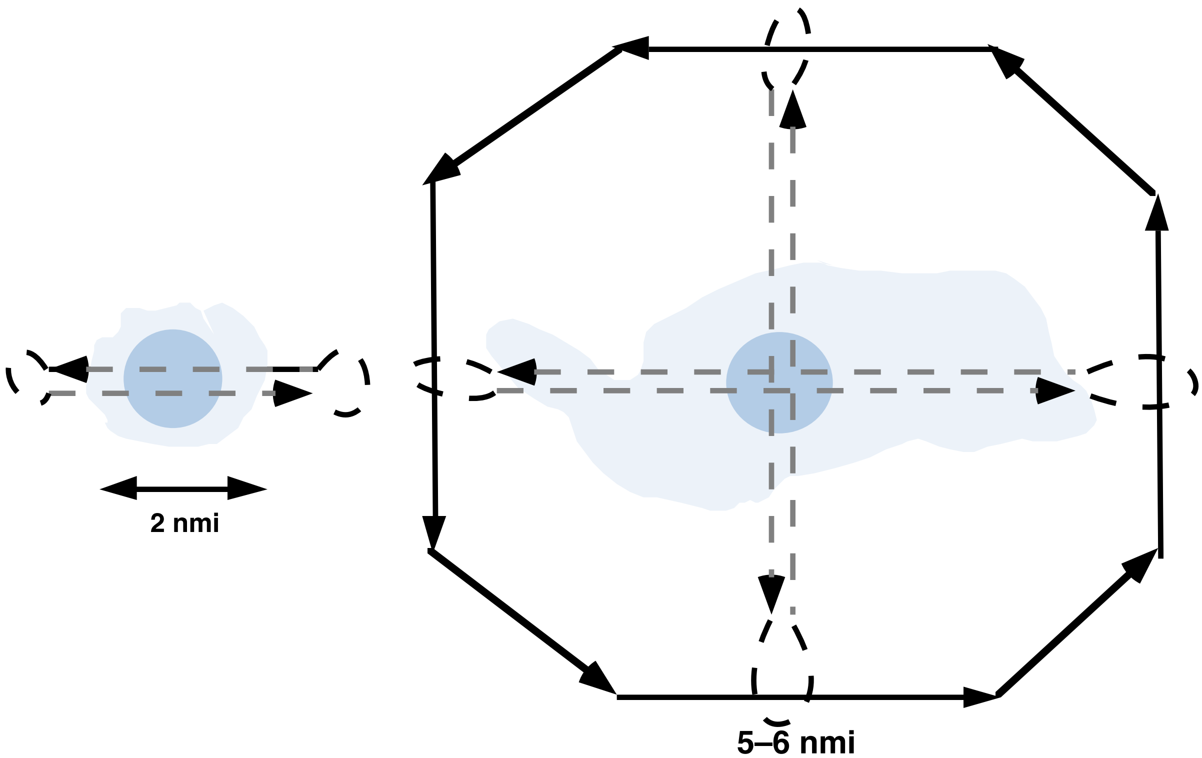


Fig. 28. (a) Initial Cloud Stage **Fig. 28. (b) Growing Stage**

- Note 1. True airspeed calibration is required.
- Note 2. The pattern may be flown along any compass heading.
- Note 3. During initial cloud stage the aircraft conducts rapid penetrations climbing with cloud top from 12,000 ft (3.5 km), climbing with the cloud top on each successive pass. Passes are separated by 1,500 ft (500 m) altitude. Climbs occur away from the convection.
- Note 4. During the growing stage the aircraft conducts circumnavigation at 5,000 ft (1.5 km) with 5-6 nmi (10-12 km) legs centered on cell to provide F/AST Doppler mapping. The circumnavigation is followed by penetration of the cell at 3,000 (1 km) or 5,000 ft (1.5 km).
- Note 5. Set the airborne Doppler radar to F/AST scan on all circumnavigation legs, and to scan perpendicular to the track on all penetration legs.

APPENDIX A:

DECISION AND NOTIFICATION PROCESS

DECISION AND NOTIFICATION PROCESS

The decision and notification process is illustrated in Fig. A-1. This process occurs in four steps:

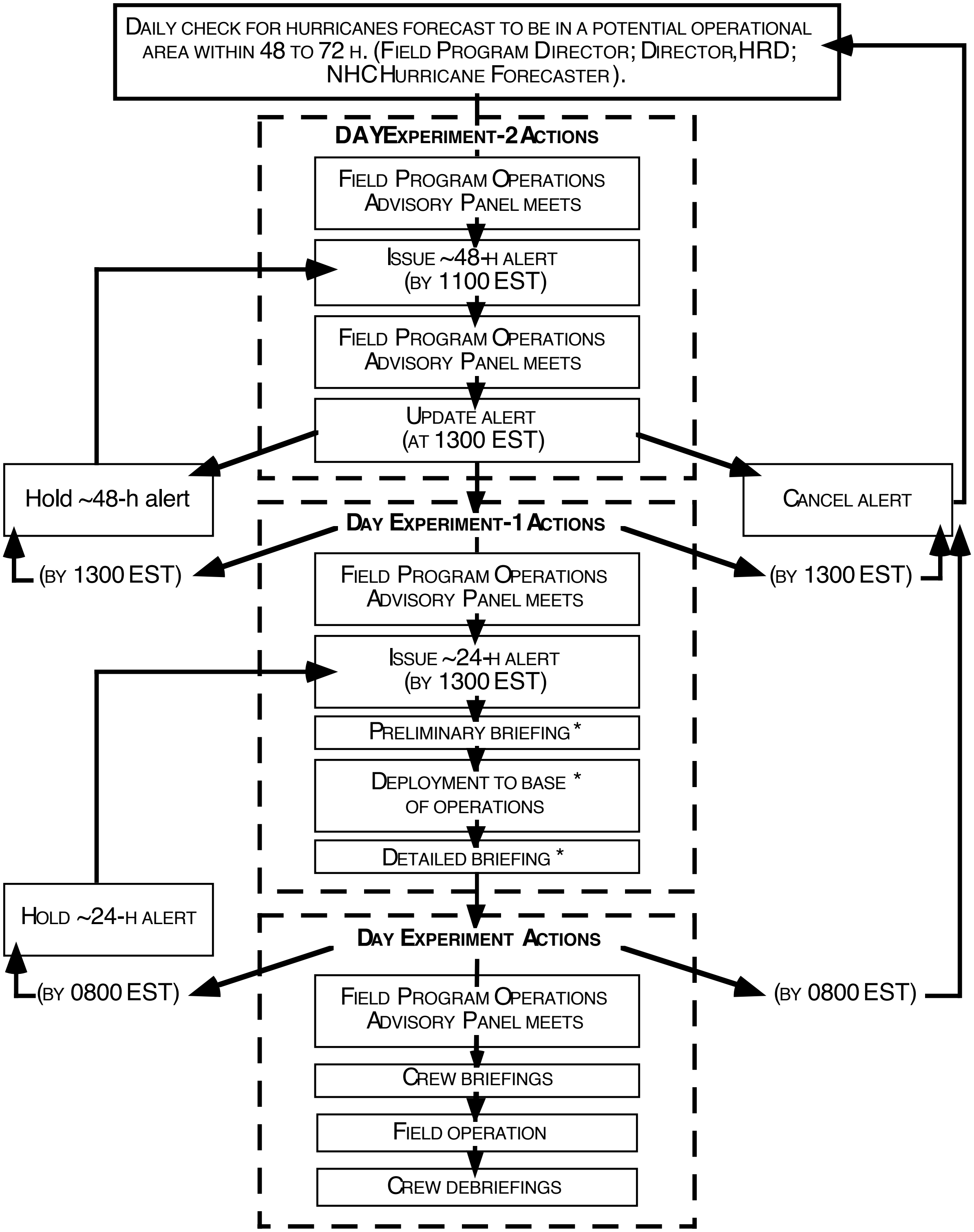
1) A research mission is determined to be probable within 72 h [field program director]. Consultation with the directors of HRD and AOC (or their designees) determines: flight platform availability, crew and equipment status, and the type of mission(s) likely to be requested.

2) The Field Program Advisory Panel [Director, HRD, Marks, M. Black, P. Black, R. Black, Cione, Dodge, Franklin, Gamache, Houston, Kaplan, Powell, Landsea, Willis, and McFadden (or AOC designee)], meets to discuss possible missions and operational modes. Probable mission determination and approval to proceed is given by the HRD director (or designee)].

3) Primary personnel are notified by the field program director [Marks].

4) Secondary personnel are notified by their primary affiliate (Table A-2).

General information, including updates of program status, are provided continuously by tape. Call (305) 221-3679 to listen to the recorded message. During normal business hours, callers should use (305) 361-4400 for other official inquiries and contacts. During operational periods, an MGOC team member is available by phone at (305) 229-4407 or (305) 221-4381. MGOC team leader and the field program director will have telepaging units. (Appropriate telepager phone numbers will be provided to program participants before the start of the field program.)



* Time of briefings and deployments are dictated by the crew, scientist, aircraft and storm locations and conditions.

Fig. A-1. Decision and notification process.

Table A-1. Primary Contacts

Name	Agency/title	Work phone
H. Willoughby	HRD/Director	305-361-4502
F. Marks	HRD/Field Program Director	305-361-4321
P. Black	HRD/Assistant Field Program Director	305-361-4320
H. Friedman	HRD/MGOC Senior Team Leader	305-361-4319
J. McFadden	AOC/Project Manager for Hurricane Research	813-828-3310 x3076
J. Parrish	AOC/Alternate Project Manager for Hurricane Research	813-828-3310 x3077
J. Pavone	CARCAH/Liaison	305-229-4474
Synoptic Analysis Branch	NESDIS/Liaison	301-763-8444 301-763-8445
K. Katsaros	AOML/Director	305-361-4302 305-361-4300
D. Konop	OAR/PA	301-713-2483
F. Lepore	TPC/NHC/PA	305-229-4404

1 DSN: Defense Switched Network (replaced Autovon).

Table A-2. Secondary Contacts

Name/group	Work phone	Contacted by
HRD participants		F. Marks/MGOC
AOC participants		J. McFadden
G. McKim/AOC	813-828-3310 x3023	J. McFadden
FAA		AOC
LT.COL Gale Carter	601-377-3207	CARCAH
53rd Wea. Recon. Sqdn.	597-3207[1]	
R. Burpee/TPC/NHC	305-229-4402	F. Marks
Steve Lyons/TSAF/TPC/NHC	305-229-4430	F. Marks/MGOC
Sr. Duty Meteorologist/NCEP	301-763-8298 301-763-8364 301-763-8076	F. Marks/MGOC
W.-C. Lee/NCAR	303-491-8814	F. Marks
P. Hildebrand/NCAR	303-497-2050	F. Marks
J. Rothermal	205-922-5965	F. Marks
S. Lord/NCEP	301-763-8005	J. Franklin
C. Velden/U. Wisconsin	608-262-9168	J. Franklin
J. Hallett/DRI	702-677-3117 702-784-6780	R. Black
R. McIntosh/U. Massachusetts	413-545-4858	P. Black
C. Swift/U. Massachusetts	413-545-2136	P. Black
I. Popstefanija/Quadrant	413-545-2136	P. Black
H. Selsor/NRL	601-688-4760	P. Black
T. Gobel/OFCM	301-427-2002	P. Black
S. Chen/U. Washington	206-543-8208	P. Black
E. Meindl/NDBC	601-688-1717	M. Powell/S. Houston
M. Burdett/NDBC	601-688-2868	M. Powell/S. Houston
R. Jensen/USACE	601-634-2101	S. Houston
S. Gill/NOS	301-713-2840	S. Houston
B. Albrecht/U. Miami	305-361-4045	P. Dodge / S. Houston
C. Fairall/NOAA/ETL	303-497-3253	P. Dodge / S. Houston
B. McCaul/U. Alabama	205-922-5837	P. Dodge/ S. Houston
J. Wurman/U. Oklahoma	405-325-7689	P. Dodge/ S. Houston

1 DSN: Defense Switched Network (replaced Autovon).

APPENDIX B:

Aircraft Scientific Instrumentation

Aircraft Scientific Instrumentation

Tables B-1 and B-2 list the basic meteorological and other parameters, and the instrumentation systems associated with these parameters, that are normally available on missions conducted with the NOAA/AOC WP-3D aircraft (N42RF and N43RF, respectively). The reader should note, however, that because of operational constraints, all of the instrumentation listed in the tables may not be available on a single sortie. Any changes in instrumentation specifications must be coordinated with AOC at the earliest possible time.

Table B-1. NOAA/AOC WP-3D (N42RF) instrumentation

I.	**METEOROLOGICAL PARAMETERS**	**INSTRUMENTATION**
	Free air temperature (derived)	Rosemount total temperature
	Static and dynamic pressure	Rosemount
	Dew point temperature	General Eastern
	Horizontal wind (computed)	INE/TAS (computed); GPS
	Vertical wind (computed)	High-resolution angle of attack, pitch angle, vertical acceleration with high-resolution fast tape capability
II.	**CLOUD PHYSICS PARAMETERS**	
	Small cloud droplet spectrum	FSSP forward scattering probe
	Cloud droplet spectrum	PMS Knollenberg 2-D Gray probe
	Hydrometeor size spectrum	PMS Knollenberg 2-D Gray probe
	Cloud liquid water	Johnson-Williams hot wire
III.	**RADIATION PARAMETERS**	
	Sea surface temperature	AOC modified PRT-5
	CO_2 air temperature	AOC modified PRT-5
IV.	**RADAR PARAMETERS**	
	Radar reflectivity	C-band PPI lower-fuselage (LF), 360° scan (horizontal) fan beam[1]
	Radar reflectivity	X-band RHI tail (TA), 360° scan (vertical)[1]
	Radial velocity	Doppler X-band RHI tail (TA), 360° scan (vertical)[1]
V.	**MISCELLANEOUS PARAMETERS**	
	Data transmission	Aircraft-satellite-data-link (ASDL)[2]
	Cloud structure; surface wind	Video photography (nose, side and vertical)
	Vertical atmospheric sounding	Dropsonde system
	Momentum flux	Friehe radome-mounted gust probe
VI.	**NAVIGATIONAL PARAMETERS**	
	Position, position update (and other required parameters)	INE and GPS
	Radar and pressure altitude	Radar and pressure altimeters

[1] LF radar data recorded every other scan. TA radar recorded every scan.

[2] One of HRD's airborne workstations will be installed on NOAA/AOC WP-3D (N42RF). Data inputs to the workstation include flight level and radar data. Data outputs to the ASDL computer.

Table B-2. NOAA/AOC WP-3D (N43RF) instrumentation (high level aircraft)

I.	**METEOROLOGICAL PARAMETERS**	**INSTRUMENTATION**
	Free air temperature (derived)	Rosemount total temperature
	Static and dynamic pressure	Rosemount
	Dew point temperature	General Eastern
	Horizontal wind (computed)	INE/TAS (computed); GPS
	Vertical wind (computed)	High-resolution angle of attack, pitch angle, vertical acceleration with high-resolution fast tape capability
II.	**CLOUD PHYSICS PARAMETERS**	
	Small cloud droplet spectrum	FSSP forward scattering probe
	Cloud droplet spectrum	PMS Knollenberg 2-D Gray probe
	Hydrometeor size spectrum	PMS Knollenberg 2-D Gray probe
	Cloud liquid water	Johnson-Williams hot wire
	Total liquid water	PMS King probe
III.	**RADIATION PARAMETERS**	
	Sea surface temperature	AOC modified PRT-5
	CO_2 air temperature	AOC modified PRT-5
IV.	**RADAR PARAMETERS**	
	Radar reflectivity	C-band PPI lower-fuselage (LF), 360° scan (horizontal) fan beam[1]
	Radar reflectivity	X-band RHI tail (TA), 360° scan (vertical)[1]
	Radial velocity	Doppler X-band RHI tail (TA), 360° scan (vertical)[1]
V.	**MISCELLANEOUS PARAMETERS**	
	Data transmission	Aircraft-satellite-data-link (ASDL)[2]
	Cloud structure; surface wind	Video photography (nose, side)
	Vertical atmospheric sounding	Dropsonde system
	Momentum flux	Friehe radome-mounted gust probe
	Surface wind speed and direction and rain rate	SFMR; C-SCAT[3]
VI.	**NAVIGATIONAL PARAMETERS**	
	Position, position update (and other required parameters)	INE and GPS
	Radar and pressure altitude	Radar and pressure altimeters

1 LF radar data recorded every other scan. TA radar recorded every scan.

2 One of HRD's airborne workstations will be installed on NOAA/AOC WP-3D (N43RF). Data inputs to the workstation include flight level and radar data. Data outputs to the ASDL computer.

3 C-SCAT includes the vertically scanning Doppler radar (VSDR)

APPENDIX C:

Calibration; Scientific Crew Lists; Data Buoys; DOD/NWS RAWIN/RAOB and NWS Coastal Land-based Radar Locations

Calibration; Scientific Crew Lists; Data Buoys; DOD/NWS RAWIN/RAOB and NWS Coastal Land-based Radar Locations

C.1 En-Route Calibration of Aircraft Systems

Instrument calibrations are checked by flying aircraft intercomparison patterns whenever possible during the hurricane field program or when the need for calibration checks is suggested by a review of the data. In addition, an overflight of a surface pressure reference is advisable en route or while on station when practicable. Finally, all flights en route to and from the storm are required to execute a true airspeed (TAS) calibration pattern. This pattern is illustrated in Fig. C-1.

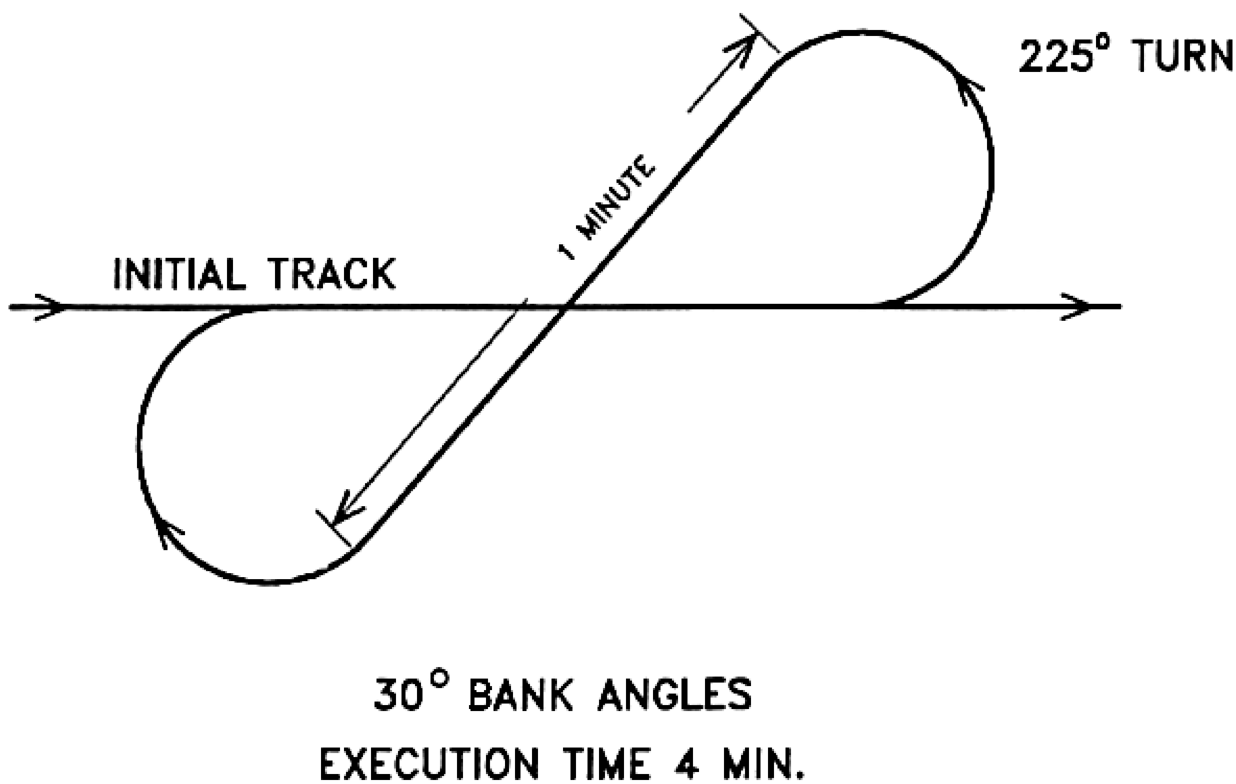


Fig. C-1 En-Route TAS calibration pattern.

C.2 Aircraft Scientific Crew Lists

Table C-2.1 Hurricane Synoptic-Flow Experiment (single-option, dual-aircraft mission)

Position	N43RF	N42RF
Lead Project Scientist	F. Marks	J. Gamache
Cloud Physics Scientist	(radar scientist)	(radar scientist)
Radar/Doppler Scientist	M. Black	S. Goldenberg
Dropsonde Scientists	J. Franklin / J. Kaplan	S. Aberson or C. Landsea
Workstation Scientist	P. Leighton	P. Dodge
C-SCAT/SFMR Scientist	P. Black	

Table C-2.2 Extended Cyclone Dynamics Experiment (single-option, two-aircraft mission)

Position	N43RF	N42RF	N43RF
Lead Project Scientist	H. Willoughby	P. Black	F. Marks
Cloud Physics Scientist	R. Black	(radar scientist)	J. Cione
Radar/Doppler Scientist	S. Goldenberg	J. Gamache	N. Dorst
Dropsonde Scientist	J. Franklin	J. Kaplan	C. Landsea
Workstation Scientist	P. Leighton	J. Griffin	P. Dodge
C-SCAT/SFMR Scientist	M. Black		M. Black

Table C-2.3 Vortex Motion and Evolution Experiment (single-option, dual-aircraft mission)

Position	N43RF	N42RF
Lead Project Scientist	J. Franklin	J. Gamache
Cloud Physics Scientist	R. Black	(radar scientist)
Radar/Doppler Scientist	M. Black or J. Cione	N. Dorst or S. Goldenberg
Dropsonde Scientist	F. Marks	S. Aberson or C. Landsea
Workstation Scientist	P. Leighton	P. Dodge
C-SCAT/SFMR Scientist	P. Black	

Table C-2.4 Tropical Cyclogenesis Experiment (single-option, dual-aircraft mission)

Position	N43RF	N42RF
Lead Project Scientist	P. Black	H. Willoughby
Cloud Physics Scientist	R. Black	S. Goldenberg
Radar/Doppler Scientist	J. Gamache	N. Dorst or J. Cione
Dropsonde Scientist	J. Franklin or F. Marks	
Workstation Scientist	P. Leighton	P. Dodge
C-SCAT/SFMR Scientist	M. Black	

Table C-2.5 Tropical Cyclone Windfields Near Landfall Experiment(dual-option, single-aircraft mission)

Position	N43RF
Lead Project Scientist	P. Dodge
Cloud Physics Scientist	(radar scientist)
Radar/Doppler Scientist	J. Gamache
Dropsonde Scientist	C. Landsea
Workstation Scientist	P. Leighton
C-SCAT/SFMR Scientist	P. Black

Table C-2.6 Tropical Cyclone Air-sea interaction Experiment(multi-option, single-aircraft mission)

Position	N43RF
Lead Project Scientist	P. Black
Cloud Physics Scientist	(radar scientist)
Radar/Doppler Scientist	J. Gamache
Dropsonde Scientist	J. Cione
Workstation Scientist	P. Leighton
C-SCAT/SFMR Scientist	M. Black

Table C-2.7 Rainband Structure Experiment (dual-option, dual-aircraft mission)

Position	N43RF	N42RF
Lead Project Scientist	P. Black	F. Marks
Cloud Physics Scientist	R. Black	J. Cione
Radar/Doppler Scientist	J. Gamache	N. Dorst
Dropsonde Scientist	J. Franklin	S. Goldenberg
Workstation Scientist	P. Leighton	P. Dodge
C-SCAT/SFMR Scientist	M. Black	

Table C-2.8 Electrification of Tropical Cyclone Convection (dual-option, single-aircraft mission)

Position	N43RF
Lead Project Scientist	R. Black
Cloud Physics Scientist	N. Dorst
Radar/Doppler Scientist	M. Black
Dropsonde Scientist	S. Goldenberg
Workstation Scientist	P. Leighton
C-SCAT/SFMR Scientist	P. Black

Table C-2.9 Eyewall Vertical Motion Structure Experiment

Position	N43RF	N42RF
Lead Project Scientist	F. Marks	M. Black
Cloud Physics Scientist	R. Black	N. Dorst
Radar/Doppler Scientist	J. Gamache	P. Dodge
Dropsonde Scientist	S. Aberson	S. Goldenberg
Workstation Scientist	P. Leighton	J. Griffin
C-SCAT/SFMR Scientist	P. Black	

Table C-2.10 Clouds and Climate Study:

Position	N43RF
Lead Project Scientist	P. Willis
Cloud Physics Scientist	R. Black
Radar/Doppler Scientist	P. Dodge or J. Cione
Dropsonde Scientist	C. Landsea
Workstation Scientist	P. Leighton

C.3 Buoy/Platform Overflight Locations[1]

Table C-3.1 Moored Buoys (1997)

Station Identifier	Type of Station[2]		Location		Area	Special Obs/ Comments[4, 5, 6]
			Lat. (N)	Lon (W)		
44007[7]	3D	/D	43.5	70.1	PORTLAND	A
44005*[3]	6N	/D	42.9	68.9	GULF OF MAINE	A
44013[7]	3D	/D	42.4	70.7	BOSTON	---
44011*	6N	/D	41.1	66.6	GEORGES BANK	A
44008[3]	3D	/D	40.5	69.4	NANTUCKET	A
44025	3D	/D	40.3	73.2	LONG ISLAND	DW
44004*[3]	6N	/D	38.5	70.7	HOTEL	---
44009	3D	/D	38.5	74.7	DELAWARE BAY	---
44014	3D	/D	36.6	74.8	VIRGINIA BEACH	DW
41001*	6N	/D	34.7	72.6	E. HATTERAS	A
41002*	6N	/D	32.4	75.3	S. HATTERAS	---
41004[3,7]	3D	/D	32.5	79.1	EDISTO	DW
41010[3]	6N	/D	28.9	78.5	CANAVERAL EAST	---
41009	10D	/D	28.5	80.2	CANAVERAL	---
42036	3D	/D	28.5	84.5	W. TAMPA	DW
42003*[3]	10D	/V	25.9	85.9	E. GULF	A
42040	3D	/D	29.2	88.3	MOBILE SOUTH	A
42007[7]	12D	/V	30.1	88.8	OTP	A
42001*	10D	/V	25.9	89.7	MID GULF	A
42002*	10D	/V	25.9	93.6	W. GULF	A
42035[3]	3D	/V	29.3	94.4	GALVESTON	---
42039[3]	3D	/D	28.8	86.0	PENSACOLA	A

[1] Tables C-3.1 and C-3.4 were updated with information from the **Data Platform Status Report (May 1, 1997)**, NOAA/National Data Buoy Center (NDBC), Stennis Space Center, MS 39529-6000, for the period **May 1-8, 1997**. (Also, the NDBC report lists the location of drifting buoys o/a **May 1-8, 1997**). See subsequent editions of this weekly NDBC report for later information. Tables C-3.2, C-3.3, and portions of C-3.4 were updated with information from **National Weather Service Offices and Stations** (April 1997), NOAA/NWS, W/MB31, Silver Spring, MD.

[2]

Hull Type			Anemometer Height
10D	-	10-m discus buoy	10.0 m
6N	-	6-m NOMAD buoy	5.0 m
3D	-	3-m discus buoy	5.0 m

Payload types: /G = GSBP; /D = DACT; /V = VEEP.

[3] Note remarks section of NDBC report (**May 1, 1997**); see latest edition of NDBC **Data Platform Status Report** for current status.

[4] AFOS PIL headers (for formatted data) include: MIABOYDAT; NMCBOYOC5; NMCBOYOC6; and NMCBOYOC7. (Contact NHC/Comms for specific information.)

[5] Group identifiers (for coded data) include: SNVD15 KWBC; SMVD16 KWBC; and SNVD17 KWBC. (Contact NHC/Comms for specific information).

[6] A = 10-min data (continuous); R = rainfall; DW = directional wave spectra.

[7] Station may not be funded throughout FY97.

* Base funded station of the National Weather Service (NWS); however, all stations report data to NWS.

Table C-3.2 Automated over-water surface buoy and instrumented platform locations (1997)

Station Identifier/Name	Type of Station[1]	Location Lat. (N)	Location Lon (W)	Area
MEBF1/S. Melbourne Beach	DARDC	28.1	80.6	FL COAST
MIBF/Miami Beach	DARDC	25.8	80.1	FL COAST
FLGF/Flamingo	DARDC	25.2	80.9	FL COAST
NAPF/Naples	DARDC	26.1	81.8	FL COAST
—/Sunshine Skyway Bridge	PORTS	27.7	82.6	FL COAST
TUPF1/Turkey Point	DARDC	29.9	84.5	FL COAST
—/Springmaid Pier	DARDC	36.7	78.9	SC COAST
—/Holden Beach	DARDC	33.9	78.7	NC COAST
—/Kure Beach	DARDC	34.0	77.9	NC COAST
—/Topsail Beach	DARDC	34.5	77.4	NC COAST
Mobile Platforms:				
P92/Salt Point	RAMOS	29.5	91.6	GULF MEX

[1] AMOS = Automatic Marine (Meteorological) Observing Station (full parameter)
DARDC = Device for Automatic Remote Data Collection (partial parameter)
PORTS = Physical Oceanographic Real-Time System (NOS)
RAMOS = Remote Automatic Meteorological Observing Station (full parameter)

Table C-3.3 Partial list of Automated Surface Observing System (ASOS) sites in coastal locations (1997)

Station Identifier	Type of Station[1]	Station Name
DOMESTIC		
Alabama:		
EET	FAA	Alabaster
79J	DODa	Andalusia
ANB	FAA	Anniston
BHM	FAA	Birmingham
KDCU	FAA	Decatur
DHN	FAA	Dothan
SXS	NWS	Enterprise
KGZH	FAA	Evergreen
LOR	DODa	Fort Rucker
KHSV	NWS	Huntsville
KBFM	FAA	Mobile
KMOB	NWS	Mobile
KMGM	NWS	Montgomery
KMSL	FAA	Muscle Shoals
PAFB1	DODa	Patrick AFB
TOI	FAA	Troy
TCL	FAA	Tuscaloosa
Connecticut:		
KBDR	NWS	Bridgeport
DXR	FAA	Danbury
GON0	FAA	Groton/New London
KHFD	FAA	Hartford
HVN	FAA	New Haven
KIJD	FAA	Willimantic
KBDL	NWS	Windsor Locks
Delaware:		
GED	FAA	Georgetown
KILG	NWS	Wilmington
Florida:		
AQQ	NWS	Apalachicola
KNAE	DODn	Astor
KBKV	FAA	Brooksville
CCAS1	FAA	Cape Canaveral
KNZC	DODn	Cecil
CEW	FAA	Crestview
CTY	NWS	Cross City
KDAB	NWS	Daytona Beach
KDTS	FAA	Destin
FLL	FAA	Fort Lauderdale
FXE	FAA	Fort Lauderdale
FMY	FAA	Fort Myers
RSW	FAA	Fort Myers
FPR	FAA	Fort Pierce
GNV	FAA	Gainesville
HWO	FAA	Hollywood
CRG	FAA	Jacksonville
KJAX	NWS	Jacksonville
KNIP	DODn	Jacksonville
KEYW	NWS	Key West
KNQX	DODn	Key West
KLEE	FAA	Leesburg
MTH	FAA	Marathon
KMAI	FAA	Marianna
NRB	DODn	Mayport
KMIA	NWS	Miami
OPF	FAA	Miami
TMB	FAA	Miami
KNDZ	DODn	Milton
KNFJ	DODn	Milton
KNSE	DODn	Milton
MLB	FAA	Melbourne
KRRF	FAA	New Port Richey
KMCO	NWS	Orlando
ORL	FAA	Orlando
PFN	FAA	Panama City
KNPA	DODn	Pensacola
PNS	FAA	Pensacola
40J	NWS	Perry-Foley
PMP	FAA	Pompano Beach
KPGD	FAA	Punta Gorda
SRQ	FAA	Sarasota/Bradenton
PIE	FAA	St. Petersburg/Clearwater
KTLH	NWS	Tallahassee
KTPA	NWS	Tampa
VRB	FAA	Vero Beach
KPBI	NWS	West Palm Beach
KGIF	FAA	Winter Haven
Georgia:		
ABY	FAA	Albany
AMG	FAA	Alma
KAHN	NWS	Athens
FTY	FAA	Atlanta
KATL	NWS	Atlanta
PDK	FAA	Atlanta
KAGS	NWS	Augusta
KDNL	FAA	Augusta
SSI	FAA	Brunswick
VPC	FAA	Cartersville
KCSG	NWS	Columbus
KGVL	FAA	Gainesville
KNBQ	DODn	Kings Bay
KMCN	NWS	Macon
KFFC	FAA	Peachtree City
KRMG	NWS	Rome
KSAV	NWS	Savannah
Louisiana:		
AEX	FAA	Alexandria
KESF	FAA	Alexandria
KBTR	NWS	Baton Rouge

Louisiana (continued):

Station Identifier	Type of Station[1]	Station Name
FTPK1	DODa	Fort Polk (JRTC)
FTPK3	DODa	Fort Polk (JRTC)
LFT	FAA	Lafayette
KLCH	NWS	Lake Charles
MLU	FAA	Monroe
ARA	FAA	New Iberia
KMSY	NWS	New Orleans
KNBG	DODn	New Orleans
NEW	FAA	New Orleans
P92	NWS	Salt Point
KDTN	FAA	Shreveport
SHV	NWS	Shreveport
6R0	FAA	Slidell
7R1	NWS	Venice
KTVR	FAA	Vicksburg/Tallulah

Maine:

Station Identifier	Type of Station[1]	Station Name
AUG	FAA	Augusta
KNHZ	DODn	Brunswick
KCAR	NWS	Caribou
KFVE	FAA	Frenchville
KIZG	FAA	Fryeburg
HUL	FAA	Houlton
KMLT	FAA	Millinocket
KPWM	NWS	Portland
KIWI	FAA	Wiscasset

Maryland:

Station Identifier	Type of Station[1]	Station Name
KNAK	DODn	Annapolis
BWI	NWS	Baltimore
HGR	FAA	Hagerstown
N80	FAA	Ocean City
KNHK	DODn	Patuxent River
SBY	FAA	Salisbury
KNUI	DODn	St. Inigoes

Massachusetts:

Station Identifier	Type of Station[1]	Station Name
BED	FAA	Bedford
BVY	BVY	Beverly
KBOS	NWS	Boston
KCQX	FAA	Chatham
FIT	FIT	Fitchburg
KHYA	FAA	Hyannis
KLWM	FAA	Lawrence
ACK	FAA	Nantucket
KEWB	FAA	New Bedford
KAQW	FAA	North Adams
OWD	FAA	Norwood
KORE	FAA	Orange
PSF	FAA	Pittsfield
KPYM	FAA	Plymouth
TAN	FAA	Taunton
MVY	FAA	Vineyard Haven
KORH	NWS	Worcester

Mississippi:

Station Identifier	Type of Station[1]	Station Name
BIX1	DODn	Biloxi
BIX2	DODn	Biloxi
BIX3	DODn	Biloxi
GLH	FAA	Greenville
KGWO	FAA	Greenwood
GPT	FAA	Gulfport
HBG	FAA	Hattiesburg
HKS	FAA	Jackson
KJAN	NWS	Jackson
MCB	FAA	McComb
KMEI	NWS	Meridian
KNMM	DODn	Meridian
KNJW	DODn	Meridian Range-B
PQL	FAA	Pascagoula
KTUP	NWS	Tupelo

New Hampshire:

Station Identifier	Type of Station[1]	Station Name
KBML	FAA	Berlin
KCON	NWS	Concord
KAFN	FAA	Jaffrey
LEB	FAA	Lebanon
MHT	FAA	Manchester
6B1	FAA	Rochester
KHIE	FAA	Whitefield

New Jersey:

Station Identifier	Type of Station[1]	Station Name
12N	NWS	Andover
KACY	NWS	Atlantic City
CDW	FAA	Caldwell
MIV	FAA	Millville
VAY	FAA	Mount Holly
KEWR	NWS	Newark
N52	FAA	Somerville
FWN	FAA	Sussex
KTEB	NWS	Teterboro
TTN	FAA	Trenton

New York:

Station Identifier	Type of Station[1]	Station Name
KALB	NWS	Albany
KBGM	NWS	Binghamton
KBUF	NWS	Cheektowaga
DSV	FAA	Dansville
KDKK	FAA	Dunkirk
ELM	FAA	Elmira
FRG	FAA	Farmingdale
KN00	FAA	Fulton
GFL	FAA	Glens Falls
ISP	FAA	Islip
MSS	FAA	Massena
KMTP	NWS	Montauk
MGJ	FAA	Montgomery
NYC	NWS	New York City
KJFK	NWS	New York City
LLGA	NWS	New York City

Station Identifier	Type of Station[1]	Station Name
New York (continued):		
PEO	FAA	Penn Yan
PLB	FAA	Plattsburgh
POU	FAA	Poughkeepsie
KROC	NWS	Rochester
SLK	FAA	Saranac Lake
HWV	FAA	Shirley
KSYR	NWS	Syracuse
UCA	FAA	Utica
ART	FAA	Watertown
ELZ	FAA	Wellsville
FOK	FAA	Westhampton Beach
HPN	FAA	White Plains
North Carolina:		
KAVL	NWS	Asheville
KNLT	DODn	Atlantic
MRH	FAA	Beaufort
IGX	DODn	Chapel Hill
CLT	NWS	Charlotte
KNKT	DODn	Cherry Point
KNIS	DODn	Cherry Point
ECG	FAA	Elizabeth City
FAY	FAA	Fayetteville
KGSO	NWS	Greensboro
KHSE	NWS	Hatteras
HKY	FAA	Hickory
KNCA	DODn	Jacksonville
LBT	FAA	Lumberton
MEB	FAA	Maxton
EQY	FAA	Monroe
EWN	FAA	New Bern
KNBT	DODn	Piney Island
RDU	NWS	Raleigh/Durham
RZZ	FAA	Roanoke Rapids
RWI	FAA	Rocky Mount-Wilson
KNJM	DODn	Swansboro
KILM	NWS	Wilmington
INT	FAA	Winston Salem
Pennsylvania:		
KABE	NWS	Allentown
AOO	FAA	Altoona
KBFD	FAA	Bradford
N97	FAA	Clearfield
N88	FAA	Doylestown
KERI	NWS	Erie
CXY	FAA	Harrisburg
JST	FAA	Johnstown
LNS	FAA	Lancaster
K2G6	FAA	Meadville
KPHL	NWS	Philadelphia
KPNE	NWS	Philadelphia
AGC	FAA	Pittsburgh
KPIT	NWS	Pittsburgh
PTW	FAA	Pottstown
SEG	FAA	Selinsgrove
KAVP	NWS	Wilkes-Barre/Scranton
KIPT	NWS	Williamsport
KNXX	DODn	Willow Grove
THV	FAA	York
Rhode Island:		
KUUU	FAA	Newport
KPVD	NWS	Providence
WST	FAA	Westerly
South Carolina:		
AND	FAA	Anderson
KNBC	DODn	Beaufort
KCHS	NWS	Charleston
CEU	FAA	Clemson
CUB	FAA	Columbia
KCAE	NWS	Columbia
FLO	FAA	Florence
KGSP	NWS	Greer
GMU	FAA	Greenville
GRD	FAA	Greenwood
CRE	FAA	Myrtle Beach North
NEXC	DODn	Navelexcen
KOGB	FAA	Orangeburg
29J	FAA	Rock Hill
Texas:		
KABI	NWS	Abilene
ALI	FAA	Alice
KAMA	NWS	Amarillo
LBX	FAA	Angleton/Lake Jackson
F54	FAA	Arlington
KAUS	NWS	Austin
KBPT	NWS	Beaumont/Port Arthur
BSM	FAA	Bergstrom
KBGD	FAA	Borger
KBRO	NWS	Brownsville
KBMQ	FAA	Burnet
KCDS	FAA	Childress
KCLL	FAA	College Station
KCXO	FAA	Conroe
KCRP	NWS	Corpus Christi
KNGP	DODn	Corpus Christi
KNGW	DODn	Corpus Christi
KNVT	DODn	Corpus Christi
KCRS	FAA	Corsicana
COT	FAA	Cotulla
DHT	FAA	Dalhart
DAL	FAA	Dallas
RBD	FAA	Dallas
KDFW	NWS	Dallas/Fort Worth
KDRT	NWS	Del Rio
KDTO	FAA	Denton

Station Identifier	Type of Station[1]	Station Name
Texas (continued):		
6R6	NWS	Dryden
KELP	NEW	El Paso
KFST	FAA	Fort Stockton
AFW	FAA	Fort Worth
FTW	FAA	Fort Worth
KNFW	DODn	Fort Worth
KGLS	FAA	Galveston
KGDP	NWS	Guadalupe Pass
KHRL	FAA	Harlingen
KHDO	FAA	Hondo
DWH	FAA	Houston
KIAH	NWS	Houston
KTO2	FAA	Houston
KUTS	FAA	Huntsville
KJCT	NWS	Junction
KNQI	DODn	Kingsville
DLF	DODa	Laughlin
GGG	FAA	Longview
KLBB	NWS	Lubbock
LFK	FAA	Lufkin
KMFE	FAA	McAllen
TKI	FAA	McKinney
KNMT	DODn	McMullen
KMAF	NWS	Midland
MWL	FAA	Mineral Wells
K3R5	FAA	New Braunfels
E02	FAA	Odessa
KNOG	DODn	Orange Grove
KGDP	NWS	Pine Springs
T31	FAA	Port Isabel
KRKP	FAA	Rockport
KSJT	NWS	San Angelo
KSAT	NWS	San Antonio
SSF	FAA	San Antonio
P07	NWS	Sanderson
KTRL	FAA	Terrel
TYR	FAA	Tyler
KVCT	NWS	Victoria
KACT	NWS	Waco
KSPS	NWS	Wichita Falls
INK	FAA	Wink
Virginia:		
KOFP	FAA	Ashland
DAN	FAA	Danville
KNFE	DODn	Fentress
KLYH	NWS	Lynchburg
PHF	FAA	Newport News
KNGU	DODn	Norfolk
KORF	NWS	Norfolk
KNYG	DODn	Quantico
KRIC	NWS	Richmond
KROA	NWS	Roanoke
KNTU	DODn	Virginia Beach
AKQ	NWS	Wakefield
WAL	NWS	Wallops Island
DCA	NWS	Washington, DC
KIAD	NWS	Washington, DC
CARIBBEAN		
Puerto Rico:		
TJNR	DODn	Roosevelt Roads
TJSJ	NWS	San Juan
Virgin Islands:		
STT	FAA	Charlotte Amalie
STX	FAA	Christiansted

[1] DODa = Department of Defense (Air Force) site;
DODn = Department of Defense (Navy) site;
FAA = Federal Aviation Administration site;
NWS = National Weather Service site.

Table C-3.4 C-MAN sites (1997)[1,2]

Station Identifier	Station Name/ Payload Type	Location Lat. (N)	Lon (W)	Area	Comments[4]	Height (m)
MDRM1*	Mt. Desert Rock, ME/D	44.0	68.1	ME COAST	---	22.6
MISM1*	Matinicus Rock, ME/D	43.8	68.9	ME COAST	---	16.5
IOSN3*[3]	Isle of Shoals, NH/D	43.0	70.6	NH COAST	---	19.2
BUZM3*	Buzzards Bay, MA/V	41.0	71.0	MA COAST	A	24.0
ALSN6*[3]	Ambrose Light, NY/V	40.5	73.8	NY COAST	---	49.1
TPLM2*[3]	Thomas Point, MD/V	38.9	76.4	MD COAST	---	8.0
CHLV2*	Chesapeake Light, VA/D	36.9	75.7	VA COAST	A	43.3
DUCN7	Duck Pier, NC/V	36.2	75.7	NC COAST	A	20.4
DSLN7*[3]	Diamond Shoals Light, NC/D	35.2	75.3	NC COAST	A, DP	46.6
CLKN7*	Cape Lookout, NC/V	34.6	76.5	NC COAST	A	9.8
FPSN7*[3]	Frying Pan Shoals, NC/D	33.5	77.6	NC COAST	A	44.2
FBIS1*	Folly Island, SC/D	32.7	79.9	SC COAST	A	9.8
SVLS1*[3]	Savannah Light, GA/D	32.0	80.7	GA COAST	A	29.9
SPGF1*[3]	Settlement Point, GBI/V	26.7	79.0	GR BAHAMA	A	9.8
SAUF1*	St. Augustine, FL/V	29.9	81.3	FL COAST	A	8.2
LKWF1*	Lake Worth, FL/V	26.6	80.0	FL COAST	A	7.6
FWYF1	Fowey Rocks, FL/V	25.6	80.1	FL COAST	A	9.3
MLRF1*	Molasses Reef, FL/V	25.0	80.4	FL COAST	---	15.8
SMKF1*	Sombrero Key, FL/V	24.6	81.1	FL COAST	---	48.5
SANF1	Sand Key, FL/V	24.5	81.9	FL COAST	A	13.1
LONF1	Long Key, FL/V	24.8	80.9	FL COAST	---	7.0
DRYF1	Dry Tortugas, FL/V	24.6	82.9	FL COAST	---	5.7
VENF1*[3]	Venice, FL/V	27.1	82.4	FL COAST	A	7.9
CDRF1	Cedar Key, FL/V	29.1	83.0	FL COAST	A	10.1
CSBF1*	Cape San Blas, FL/V	29.7	85.4	FL COAST	A	9.8
KTNF1	Keaton Beach, FL/V	29.8	83.6	FL COAST	A	10.1
DPIA1*	Dauphin Island, AL/V	30.2	88.1	AL COAST	---	9.8
BURL1*	Southwest Pass, LA/D	28.9	89.4	LA COAST	A	33.8
GDIL1*[3]	Grand Isle, LA/V	29.3	90.0	LA COAST	A	15.8
SRST2*	Sabine, TX/V	29.7	94.1	TX COAST	A	12.5
PTAT2*	Port Aransas, TX/V	27.8	97.1	TX COAST	A	9.8

1 Coastal-Marine Automated Network (C-MAN) stations are located on coastal headlands, piers, or offshore platforms. Payload types, shown next to the station's name (after the "/") are: D = DACT; V = VEEP; and I = Industry-supplied. C-MAN anemometer heights are listed in the **C-Man User's Guide**.

2 Data sources: (a) MIABOYDAT, NMCBOYCM1, NMCBOYCM2, NMCBOYCM5 (AFOS PIL headers for **formatted** data); (b) SXUS21 KWBC, SNVD22 KWBC (group identifiers for **coded** data). (Contact NHC/Comms for specific information).

3 Note remarks section of NDBC report (**May 16, 1997**); see latest edition of NDBC **Data Platform Status Report** for current status.

4 A = 10-min data (continuous); DP = dew point; R = rainfall; DW = directional wave spectra.

* Primarily for National Weather Service (NWS) support; however, all stations report data to NWS.

Table C-3.5 NOS next generation meteorological-tide stations (1997)*

Station Name	Location Lat. (N)	Lon (W)
Bermuda Pier, St. Georges Island	32.4	64.7
Eastport Bay, ME	44.9	67.0
Bergen Point West, NY[1]	40.6	74.2
Tolchester Beach, MD[1]	39.2	76.3
Solomons Island, MD	38.3	76.5
Kiptopeke, VA	37.2	76.0
Lewisetta, Potomac River, VA	37.5	76.5
Sewells Point, VA	37.0	76.3
Chesapeake Bay Bridge, VA	37.0	76.1
Duck, FRF Pier, NC	36.2	75.8
Cape Hatteras Fishing Pier, NC	35.2	75.6
Degaussing, Mayport NS, FL[1]	30.4	81.4
Mayport, FL	30.4	81.4
St. Augustine Beach, FL	29.9	81.3
Virginia Key, FL	25.7	80.2
Naples, FL	26.1	81.8
Port Manatee, Tampa Bay, FL[2]	27.6	82.6
St. Petersburg, FL	27.8	82.6
Port Tampa, FL[2]	27.9	82.6
McKay Bay, FL[2]	27.9	82.4
Clearwater Beach, FL	28.0	82.4
Apalachicola Bay, FL	29.7	85.0
Panama City Beach, FL	30.2	85.9
Morgans Point, TX[1]	29.7	95.0
Eagle Point, TX[1]	29.5	94.9
Port Bolivar, TX[1]	29.4	94.8
Galveston Pier, TX[1]	29.3	94.8
Galveston (offshore), TX[1]	29.1	94.5
Freeport, TX	29.0	95.3
Corpus Christi, TX	27.6	97.2
Port Mansfield, TX[3]	26.6	97.4
Cochino Pequeno[1]	16.0	86.5

* Quality controlled data from these platforms can be obtained from NDBC's **Seaboard Bulletin Board Service** soon after the fact.

1 Special project stations and will be operating at least through 1997.

2 Special project stations that have no satellite radio and non-real time data.

3 NOS plans to discontinue this station during 1997.

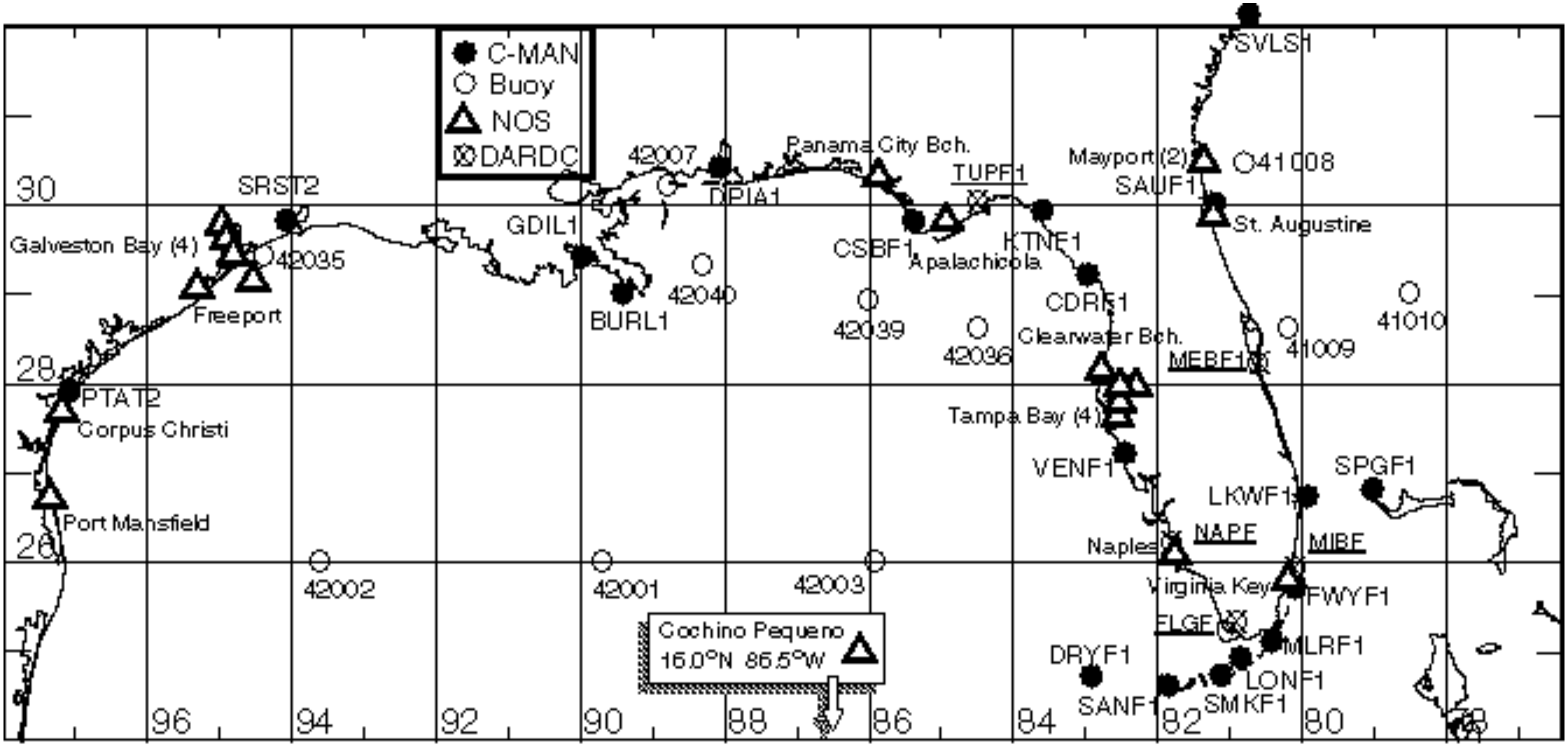


Fig. C-2. Marine buoy, C-MAN, NOS (lower case), and DARDC (underlined) locations in the Gulf of Mexico, Florida, and southern Georgia. See Tables C-3.1 -- C-3.5.

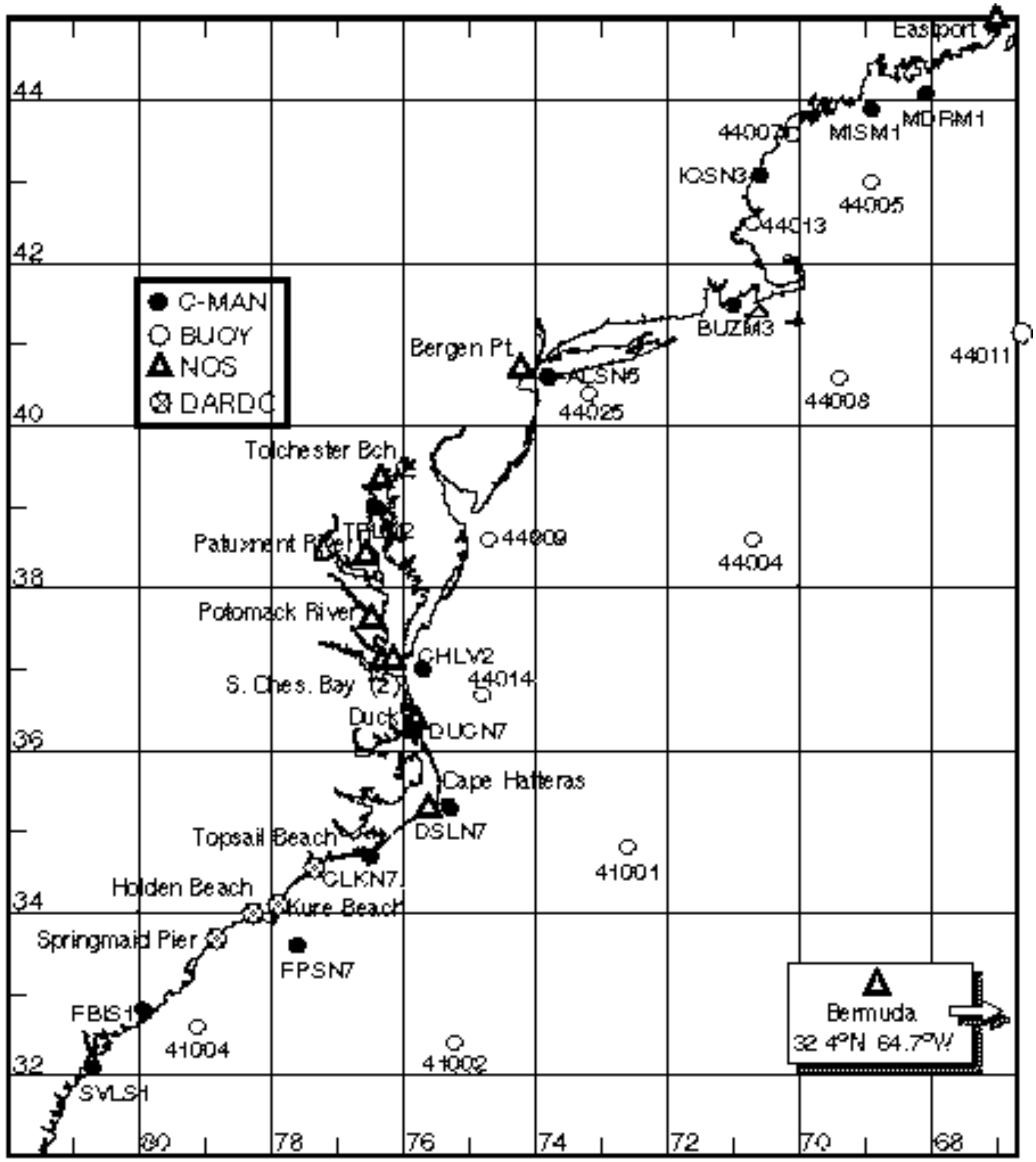


Fig C-3 Marine buoy, C-MAN, and NOS (lower case) locations for the U S. east coast.
See Tables C-3.1 -- C-3.5.

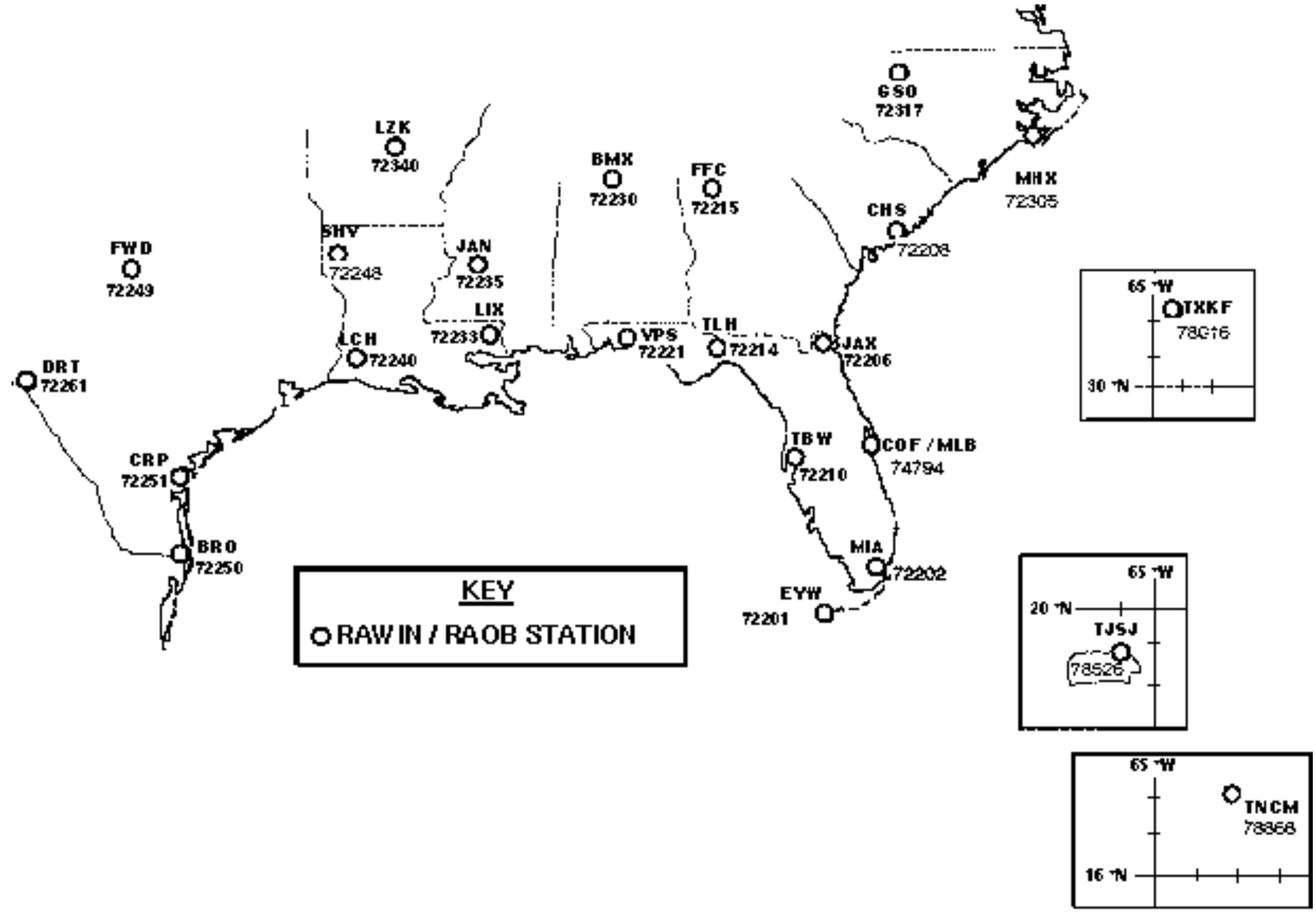


Fig. C-4. Locations of RAWIN/RAOB. See tables C-4.1 -- C-4.5 for complete information.

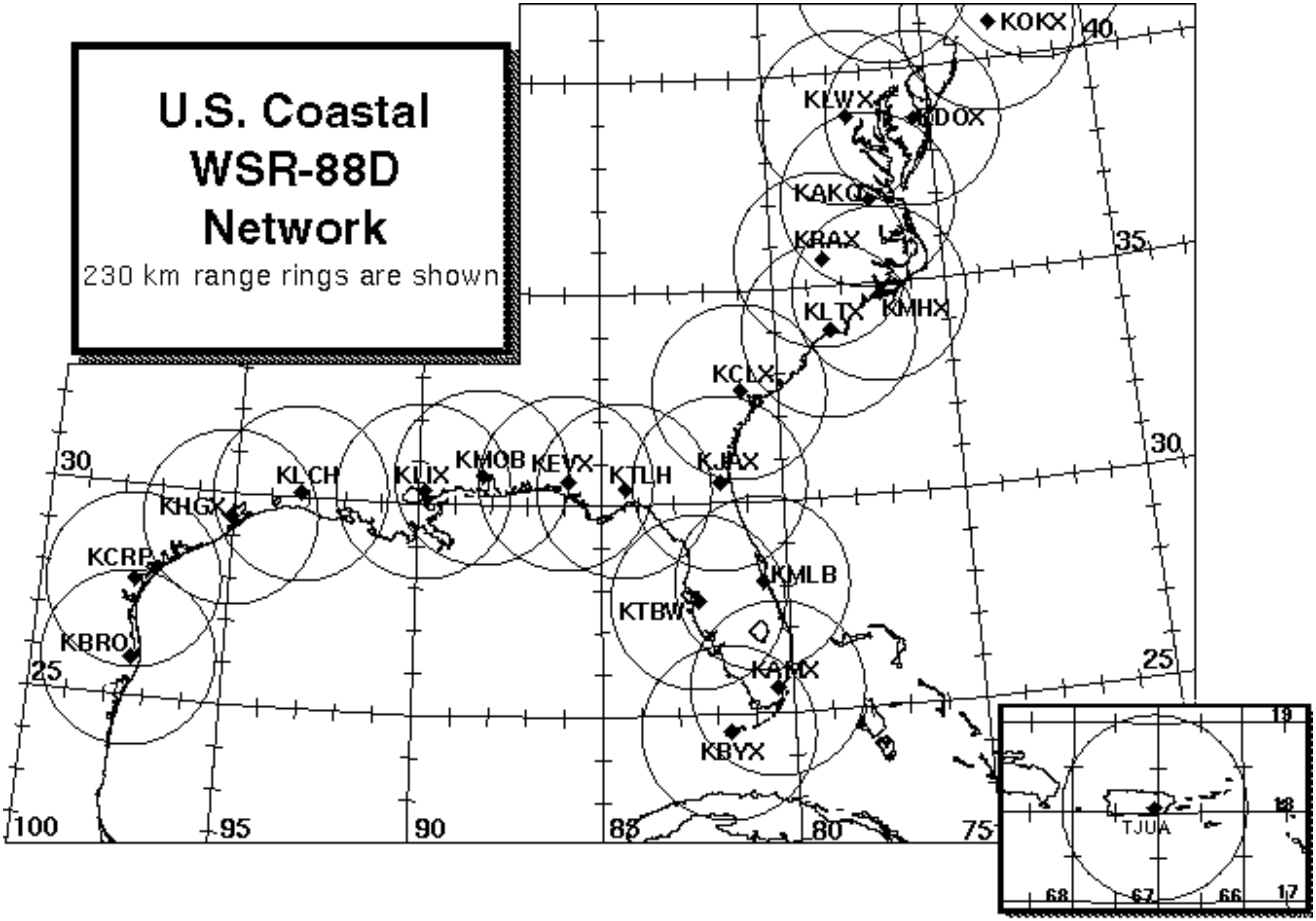


Fig. C-5. Locations of coastal WSR-88D stations. See tables C-4.1 -- C-4.5 for complete information.

PRINCIPAL DUTIES OF THE SCIENTIFIC PERSONNEL

CAUTION

Flight operations are routinely conducted in turbulent conditions. Shock-mounted electronic and experimental racks surround most seat positions. Therefore, all personnel reporting for flight will wear closed-toe shoes. In addition, it is strongly recommended that "soft" or canvas type shoes not be worn and that personal clothing be selected for appearance, safety, coverage, and fit. A light jacket is advisable as the temperature within the aircraft is kept low to protect the data systems.

Smoking is prohibited within 50 ft of the aircraft while they are on the ground. No smoking is permitted on the aircraft at any time.

GENERAL INFORMATION FOR ALL SCIENTIFIC MISSION PARTICIPANTS

Mission participants are advised to carry the proper personal identification [i.e., travel orders, "shot" records (when appropriate), and passports (when required)]. Passports will be checked by AOC personnel prior to deployment to countries requiring same. All participants must provide their own meals for in-flight consumption. Utensils, condiments, ice, beverages, and cooking and storage facilities will be provided. There will be a $1.00 seat charge on each flight to defray galley expenses.

D.1 Field Program Director

(1) Responsible to the HRD director for the implementation of the Hurricane Field Program Plan.

(2) Only official communication link to AOC. Communicates flight requirements and changes in mission to AOC.

(3) Only formal communication link between AOML and CARCAH during operations. Coordinates scheduling of each day's operations with AOC only after all (POD) reconnaissance requirements are completed between CARCAH and AOC.

(4) Convenes the Hurricane Field Program Operations Advisory Panel. This panel selects missions to be flown in comparison with others as specified in sections 9-16 of this plan.

(5) Provides for pre-mission briefing of flight crews, scientists, and others (as required).

(6) Assigns duties of field project scientific personnel.

(7) Coordinates press statements with NOAA/Public Affairs.

D.2 Assistant Field Program Director

(1) Assumes the duties of the field program director in his absence.

D.3 Field Program Ground Team Manager

(1) Has overall responsibility for field operations ground support logistics and communications.

a. Provides arrangements and support for required supplies, expendables, accommodations, etc.
b. Maintains a current source of information regarding HRD operational, personnel, and equipment status for use as directed by the field program director.

(2) Responsible for coordination and communication of field program activities as required.

(3) Responsible for updating the Miami Ground Operations Center (MGOC) as required.

(4) Provides the ground supervision and acts as the reporting officer, subject to the field program director, for all HRD project personnel.

D.4 Miami Ground Operations Center: Senior Team Leader

(1) During operations, the MGOC senior team leader is responsible for liaison between HRD base and field personnel and other organizations as requested by the field program director, the director of HRD, or their designated representatives.

D.5 Named Experiment Lead Project Scientist

(1) Has overall responsibility for the experiment.

(2) Coordinates the project and sub-project requirements.

(3) Determines the primary modes of operation for appropriate instrumentation.

(4) Assists in the selection of the mission.

(5) Provides a written summary of the mission to the field program director (or his designee) at the experiment's debriefing.

D.6 Lead Project Scientist

(1) Has overall scientific responsibility for his/her aircraft.

(2) Makes in-flight decisions concerning alterations of: (a) specified flight patterns; (b) instrumentation operation; and (c) assignment of duties to on-board scientific project personnel.

(3) Acts as project supervisor on the aircraft and is the focal point for all interaction of project personnel with operational or visiting personnel.

(4) Conducts preflight and postflight briefings of the entire crew. Completes formal check lists of instrument operations, noting malfunctions, problems, etc.

(5) Provides a written report of each mission day's operations to the field program director at the mission debriefing.

D.7 Cloud Physics Scientist

(1) Has overall responsibility for the cloud physics project on the aircraft.

(2) Briefs the on-board lead project scientist on equipment status before takeoff.

(3) Determines the operational mode of the cloud physics sensors (i.e., where, when, and at what rate to sample).

(4) Operates and monitors the cloud physics sensors and data systems.

(5) Provides a written preflight and postflight status report and flight summary of each mission day's operations to the on-board lead project scientist at the postflight debriefing.

D.8 Boundary-Layer Scientist

(1) Insures that sufficient numbers of AXCPs, AXBTs, and buoys are on the aircraft for each mission as required.

(2) Operates the AXCP, AXBT, and buoy equipment (as required) on the aircraft.

(3) Briefs the on-board lead project scientist on equipment status before takeoff.

(4) Determines where and when to release the AXCPs, AXBTs, and buoys (as appropriate) subject to clearance by flight crew.

(5) Performs preflight, inflight, and postflight checks and calibrations.

(6) Provides a written preflight and postflight status report and a flight summary of each mission day's operations to the on-board lead project scientist at the postflight debriefing.

D.9 Airborne Radar Scientist

(1) Determines optimum meteorological target displays. Continuously monitors displays for performance and optimum mode of operations. Thoroughly documents modes and characteristics of the operations.

(2) Provides a summary of the radar display characteristics to the on-board lead project scientist at the postflight debriefing.

(3) Maintains tape logs and changes magnetic tape (as needed).

(4) On most missions, an on-board radar scientist will also function in the role of the on-board Doppler radar scientist. The individual who is designated as the mission's Doppler radar scientist will be responsible for the following: (a) operate and/or monitor the system; (b) document the modes and characteristics of the system's operation; (c) document all airborne Doppler radar data collected; and (d) provide a summary of the airborne Doppler radar system's operation to the on-board lead project scientist at the postflight debriefing.

(5) During the ferry to the storm the Doppler scientist should record a tape of the sea return on either side of the aircraft at elevation angles varying from -20° through +20°. This tape will allow correction of any antenna mounting biases or elevation angle corrections.

D.10 Dropwindsonde Scientist

(1) Examines dropsonde observations for accuracy.

(2) Determines the most likely values of temperature, dew-point depression, and horizontal wind at mandatory and significant (pressure) levels.

(3) Provides final code to the data system technician for ASDL, transmission or insures correct code in the event of automatic data transmission.

D.11 Workstation Scientist

(1) Operates HRD's workstation.

(2) Runs programs that determine wind center and radar center as a function of time, composite flight-level and radar reflectivity relative to storm center and that process and code dropsonde observations.

(3) Checks data for accuracy and sends appropriate data to ASDL computer.

(4) Maintains records of the performance of the workstation and possible software improvements.

SYSTEMS OF MEASURE AND UNIT CONVERSION FACTORS

Table H-1 Systems of measure: Units, symbols, and definitions

Quantity	SI Unit	Early Metric	Maritime	English
length	meter (m)	centimeter (cm)	foot (ft)	foot (ft)
distance	meter (m)	kilometer (km)	nautical mile (nmi)	mile (mi)
depth	meter (m)	meter (m)	fathom (fa)	foot (ft)
mass	kilogram (kg)	gram (g)	pound (lb)	pound (lb)
time	second (s)	second (s)	second (s)	second (s)
speed	meter per second (mps)	centimeter per second (cm s^{-1}) kilometers per hour (km h^{-1})	knot (kt) (nmi h^{-1})	miles per hour (mph)
temperature sensible	degree Celsius (°C)	degree Celsius (°C)	-----	degree Fahrenheit (°F)
potential	degree Kelvin (°K)	degree Kelvin (°K)	-----	degree Kelvin (°K)
force	Newton (N) (kg m s^{-2})	dyne (dy) (g cm s^{-2})	poundal (pl)	poundal (pl)
pressure	Pascal (Pa) (N m^{-2})	millibar (mb) (10^3 dy cm^{-2})	inches (in) mercury (Hg)	inches (in) mercury (Hg)

Table H-2. Unit conversion factors

Parameter	Unit	Conversions
length	1 in	2.540 cm
	1 ft	30.480 cm
	1 m	3.281 ft
distance	1 nmi (nautical mile)	1.151 mi
		1.852 km
		6080 ft
	1 mi (statute mile)	1.609 km
		5280 ft
	1° latitude	59.996 nmi
		69.055 mi
		111.136 km
depth	1 fa	6 ft
		1.829 m
mass	1 kg	2.2 lb
force	1 N	10^5 dy
pressure	1 mb	10^2 Pa
		0.0295 in Hg
	1 lb ft^{-2}	4.88 kg m^{-2}
speed	1 mps	1.94 kt
		3.59 kph
	1° lat. 6 h^{-1}	10 kt

ACRONYMS AND ABBREVIATIONS

θ_e	equivalent potential temperature
ABL	atmospheric boundary-layer
A/C	aircraft
AFRES	Air Force Reserve
AOC	Aircraft Operations Center
AOML	Atlantic Oceanographic and Meteorological Laboratory
ASDL	aircraft-satellite data link
AXBT	airborne expendable bathythermograph
BL	boundary layer
CARCAH	Chief, Aerial Reconnaissance Coordinator, All Hurricanes
CDO	central dense overcast
CG	cloud-to-ground (lightning)
C-MAN	Coastal-Marine Automated Network
COARE	Coupled Ocean-Atmosphere Response Experiment
COP	Coastal Ocean Program
CP	coordination point
CRT	cathode-ray tube
C-SCAT	C-band scatterometer
CW	cross wind
DLM	deep-layer mean
DOD	Department of Defense
DRI	Desert Research Institute (at Reno)
E	vector electric field
EPAC	Eastern Pacific
ERL	Environmental Research Laboratories
ETL	Environmental Technology Laboratory
EVMSE	Eyewall Vertical Motion Structure Experiment
EVTD	extended velocity track display
FAA	Federal Aviation Administration
F/AST	fore and aft scanning technique
FEMA	Federal Emergency Management Agency
FL	flight level
FP	final point
FSSP	forward scattering spectrometer probe
GFDL	Geophysical Fluid Dynamics Laboratory
G-IV	Gulfstream IV-SP aircraft
GMT	Greenwich Mean Time (same as "UTC" or "Zulu" time)
GPS	global positioning system
HRD	Hurricane Research Division
INE	inertial navigation equipment
IP	initial point (or initial position)
IWRS	Improved Weather Reconnaissance System
JW	Johnson-Williams
LF	lower fuselage (radar)
LPS	Lead Project Scientist
MCS	mesoscale convective systems

MGOC	Miami Ground Operations Center
MPO	Meteorology and Physical Oceanography
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NDBC	NOAA Data Buoy Center
NESDIS	National Environmental Satellite, Data and Information Service
NEXRAD	Next-Generation Weather Radar (WSR-88D)
NHC	National Hurricane Center
NLDN	National Lightning Detection Network
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
ODW	Omega-based generation of dropwindsonde
OML	oceanic mixed-layer
PBL	planetary boundary layer
PDD	pseudo-dual Doppler
PMS	Particle Measuring Systems
POD	Plan of the Day
PPI	plan position indicator
PV	potential vorticity
q	specific humidity
RA	radar altitude
RAOB	radiosonde (upper-air observation)
RAWIN	rawinsonde (upper-air observation)
RECCO	reconnaissance observation
RHI	range height indicator
RSMAS	Rosenstiel School of Marine and Atmospheric Science
SAL	Saharan air layer
SFMR	stepped-frequency microwave radiometer
SLOSH	sea, lake, and overland surge from hurricanes (operational storm surge model)
SST	sea-surface temperature
TA	tail (radar)
TAS	true airspeed
TC	tropical cyclone
TCM	Tropical-Cyclone Motion (Experiment)
TEXMEX	Tropical EXperiment in MEXico
TPC	Tropical Prediction Center (at NHC)
TRMM	Tropical Rainfall Measuring Mission
UMASS	University of Massachusetts (at Amherst)
USACE	United States Army Corps of Engineers
USAF	United States Air Force
UTC	universal coordinated time (U.S. usage; same as “GMT” and "Zulu" time)
VICBAR	code name for a barotropic hurricane track prediction model (not an acronym)
VME	Vortex Motion and Evolution (Experiment)
VTD	velocity-track display
WPAC	Western Pacific
XCDX	Extended Cyclone Dynamics Experiment
Z	radar reflectivity

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