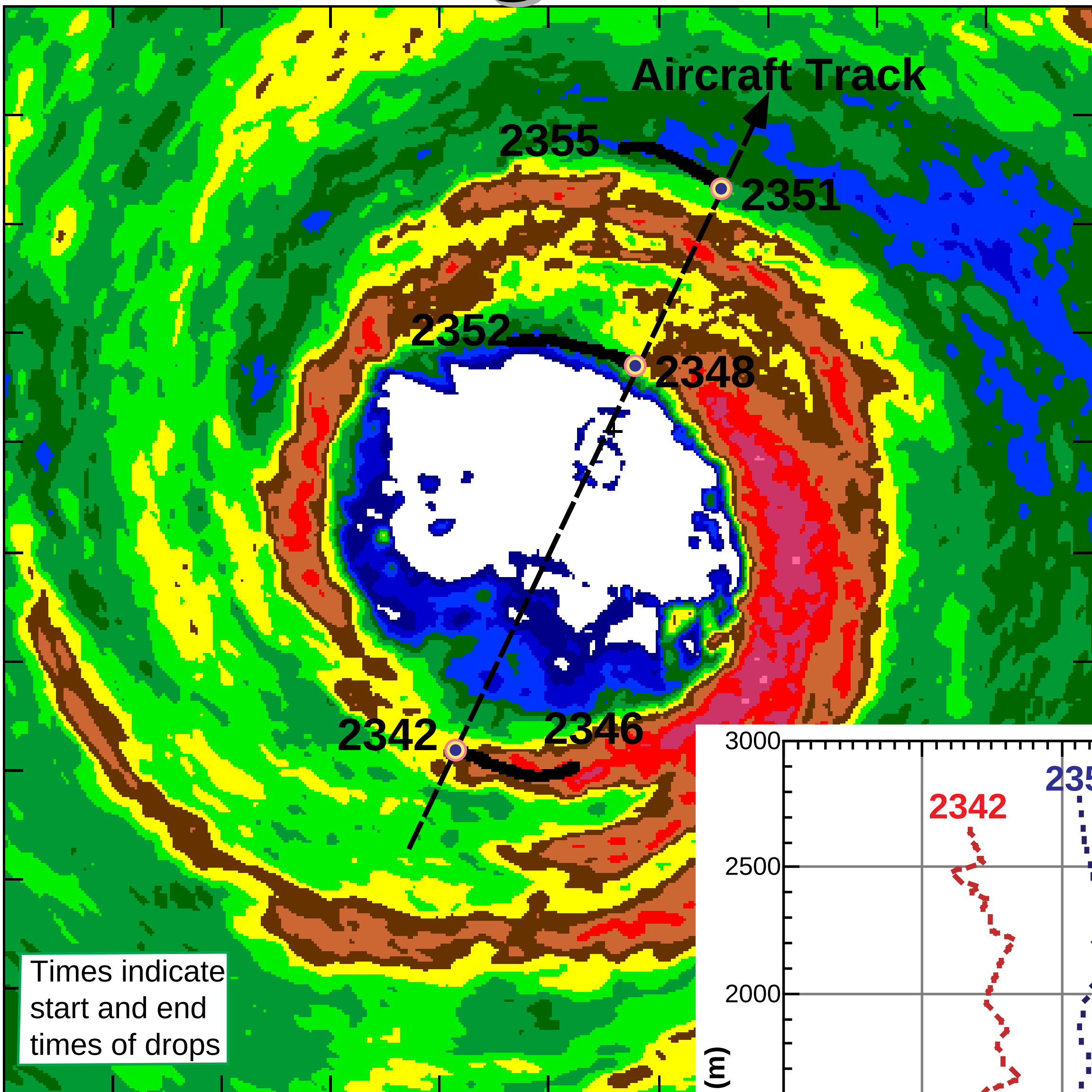
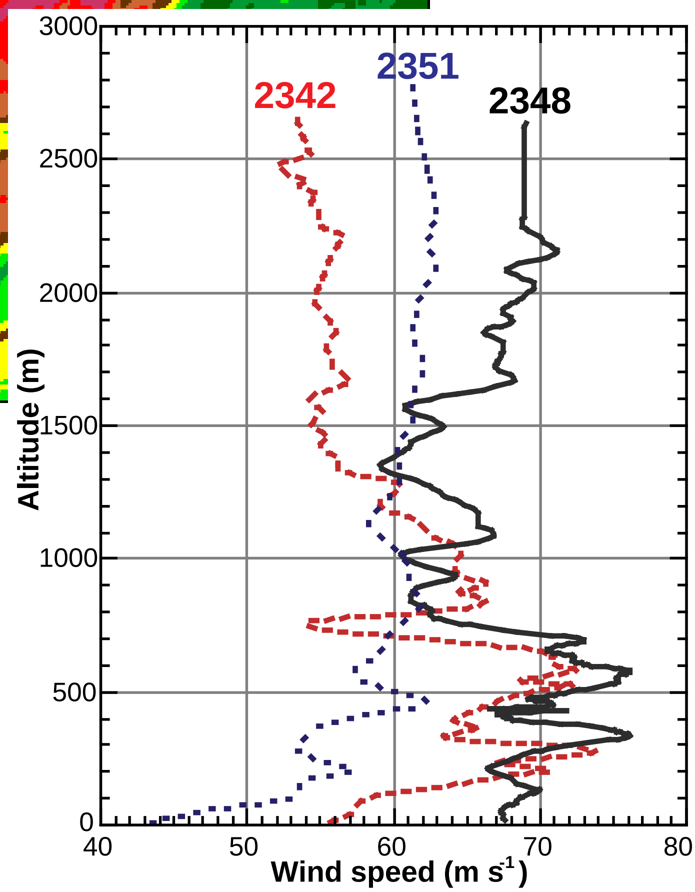
1998 Hurricane Field Program Plan





Atlantic Oceanographic and Meteorological Laboratory
Hurricane Research Division
Miami, FL

1998 Hurricane Field Program Plan

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
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20 Jun 98
Date

Cover: Vertical profiles of wind speed, obtained from the new GPS dropwindsondes, and radar reflectivity (dBZ) from the eyewall of Hurricane Guillermo on 3 August 1997. The radar imagery is a single sweep from the lower fuselage WP-3D radar at 2347 UTC. Sonde descent trajectories are superimposed on the radar reflectivity in bold black lines to indicate the location of the soundings with respect to the eyewall. The release and termination times (UTC) of the soundings are also indicated. These soundings are the first high resolution (~5 m) in-situ wind profiles ever obtained in the eyewall of a major hurricane.

CONTENTS

1998 HURRICANE FIELD PROGRAM PLAN

National Oceanic and Atmospheric Administration
Atlantic Oceanographic and Meteorological Laboratory
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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, by principal investigators at the Hurricane Research Division (HRD)/Atlantic Oceanographic and Meteorological Laboratory (AOML) of NOAA and the Mission Planning Committee for the National Aeronautics and Space Administration (NASA) Third Convection and Moisture Experiment (CAMEX-3), for the 1998 Hurricane Field Program. These experiments will be conducted with the NOAA/Aircraft Operations Center (AOC) WP-3D and Gulfstream IV-SP aircraft and the NASA DC-8 and ER-2 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 started conducting 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 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, particularly with the addition of the DC-8 and ER-2 water vapor remote sensors.

(2) Extended Cyclone Dynamics Experiment: This is a *multi-option, multi-aircraft* experiment which uses in–situ and radar data from the WP-3Ds flying at 500 mb, the G-IV or DC-8 at 200 mb, and the ER-2 near 100 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 experiment is designed to observe the structure and evolution of the inner core wind field of developing or mature hurricanes. With the addition of the DC-8 and ER-2 this becomes a *multi-option*, *multi-aircraft* experiment. 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 8 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. The possible addition of the G-IV this season will allow sampling of the upper tropospheric structure using flight-level and GPS-sondes in these developing disturbances.

(5) Tropical Cyclone Wind Fields Near Landfall: This experiment is designed to study the changes in tropical cyclones (TC) near surface wind structure near and after landfall. With the addition of the DC-8 and ER-2 this becomes a *multi-option*, *multi-aircraft* experiment. 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 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. With the addition of the DC-8 and ER-2 this becomes a *multi-option*, *multi-aircraft* experiment. This experiment seeks to address this issue through single-level aircraft penetrations using GPS-sondes, flight-level data, air-deployed drifting buoys, AXBTs, AXCPs, AXCTDs, Surface Contour Radar (SCR), C-band scatterometer (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 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. With the addition of the DC-8 and ER-2 this becomes a *multi-option*, *multi-aircraft* experiment. 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. Two stand-alone single aircraft modules which can be flown with other experiments: (1) the Rainband Module (lasting 30-60 min); and (2) the Rainband Thermodynamics Module (lasting 1-1.5 h) are also included.

(8) Electrification of Tropical Cyclone Convection Experiment: This experiment is designed to seek out the electrically active convection in TCs for in-depth study. With the addition of the DC-8 and ER-2 this becomes a *multi-option*, *multi-aircraft* experiment. The first option uses the Desert Research Institute (DRI) electric field mills, the DRI induction ring, and the LIP instrument on the DC-8 and ER-2 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 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.

With the addition of the DC-8 and ER-2 this becomes a *multi-option*, *multi-aircraft* experiment. It utilizes both NOAA WP-3D aircraft flying highly coordinated flight patterns to map the three-dimensional structure of eyewall vertical motions. The DC-8 ARMAR Doppler radar and the ER-2 vertically pointing EDOP radar will provide additional vertical incidence Doppler data. The target storm must have an eyewall (or a developing one) with significant areas of deep convection.

(10) Clouds and Climate: This experiment uses the airborne Doppler radar and microphysics instrumentation to accumulate a data base of cloud precipitation properties over a wide range of environments. With the addition of the DC-8 and ER-2 this becomes a *single-option*, *multi-aircraft* experiment. This study emphasizes the exploitation of airborne in-situ microphysics 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, particularly the NASA Tropical Rain Measurement Mission (TRMM). This experiment will be coordinated with other TRMM validation experiments under the auspices of CAMEX-3 and the Texas-Florida Underflight (TEFLUN) Experiment.

CONCEPT OF OPERATIONS

1. Location

The primary base of operations for the NOAA aircraft 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). The primary base of operations for the NASA aircraft will be Patrick AFB, Florida with no planned deployments.

Deployments of the NOAA aircraft 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. In the event of a NOAA aircraft deployment to Mexico after 15 September 1998, the NASA aircraft will deploy to NASA Dryden Flight Research Center for joint flights in the eastern Pacific.

2. Field Program Duration

The hurricane field research program will be conducted from 22 July through 31 October 1998. The CAMEX-3 will be conducted from 6 August through 23 September 1998.

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, AOC, and NASA CAMEX-3 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. If 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 1998 Hurricane Field Program (on or about 22 July through 31 October). When possible, the G-IV jet aircraft will be used with the WP-3Ds during the Synoptic-Flow or Genesis Experiment. The NASA DC-8 (NA817) , equipped as shown in Table B-3 (Appendix B), will be available for research operations from 11 August through 23 September. The NASA ER-2 (NA809), equipped as shown in Table B-4 (Appendix B), will be available for research operations from 6 August through 23 September.

5. Field Operations

5.1 Scientific Leadership Responsibilities

The implementation of HRD's 1998 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.

During CAMEX-3 the field program director will coordinate any joint research missions with the NASA CAMEX-3 Mission Planning Committee, who are responsible for the NASA mission objectives. While in flight the designated NASA CAMEX-3 lead scientists and flight coordinators are in charge of the scientific missions being flown.

5.2 Aircraft Scientific Crews

Tables C-2.1 through C-2.10 (Appendix C) list the NOAA scientific crew members needed to conduct the 1998 hurricane field experiments. Actual named assignments may be adjusted on a case-by-case basis. Operations in 1998 will include completion of detailed records by each scientific member while on the aircraft. General checklists of NOAA science-related functions are included in E.2 through E.6 (Appendix E).

5.3 Principal Duties of the Scientific Personnel

A list of primary duties for each NOAA scientific personnel position is given in D.1 through D.12 (Appendix-D).

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) 221-4381 (HRD/TPC/NHC) or at (305) 361-4400 (HRD/AOML). At other times, an updated, automated telephone answering machine [(305) 221-3679] 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, CAMEX-3, 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 and CAMEX-3 personnel who have completed a flight will provide information to MGOC, as required.

6. Data Management

All requests for NOAA data gathered during the 1998 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 NOAA 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.

A CAMEX-3 objective is to obtain water vapor profiles around the storm's environment using the LASE instrument on the DC-8 (Appendix B). This mission is best when coordinated with a multi-plane Synoptic Flow Experiment, whose GPS-sondes will provide ground truth for the water vapor profiles. A sample mission is shown in Fig. 3. The DC-8 aircraft and the ER-2 will begin their missions at the same time as the two WP-3D and G-IV aircraft. Subject to safety and operational constraints, the DC-8 will climb to the 200-mb level (about FL 410) or above and the ER-2 climbs to 65,000 ft. *G-IV dropwindsondes may pose a hazard to the DC-8 aircraft. If a simultaneous G-IV surveillance mission is conducted it is particularly important that the DC-8 mission avoid conflicts with the operational requirements.*

HURRICANE SYNOPTIC FLOW EXPERIMENT

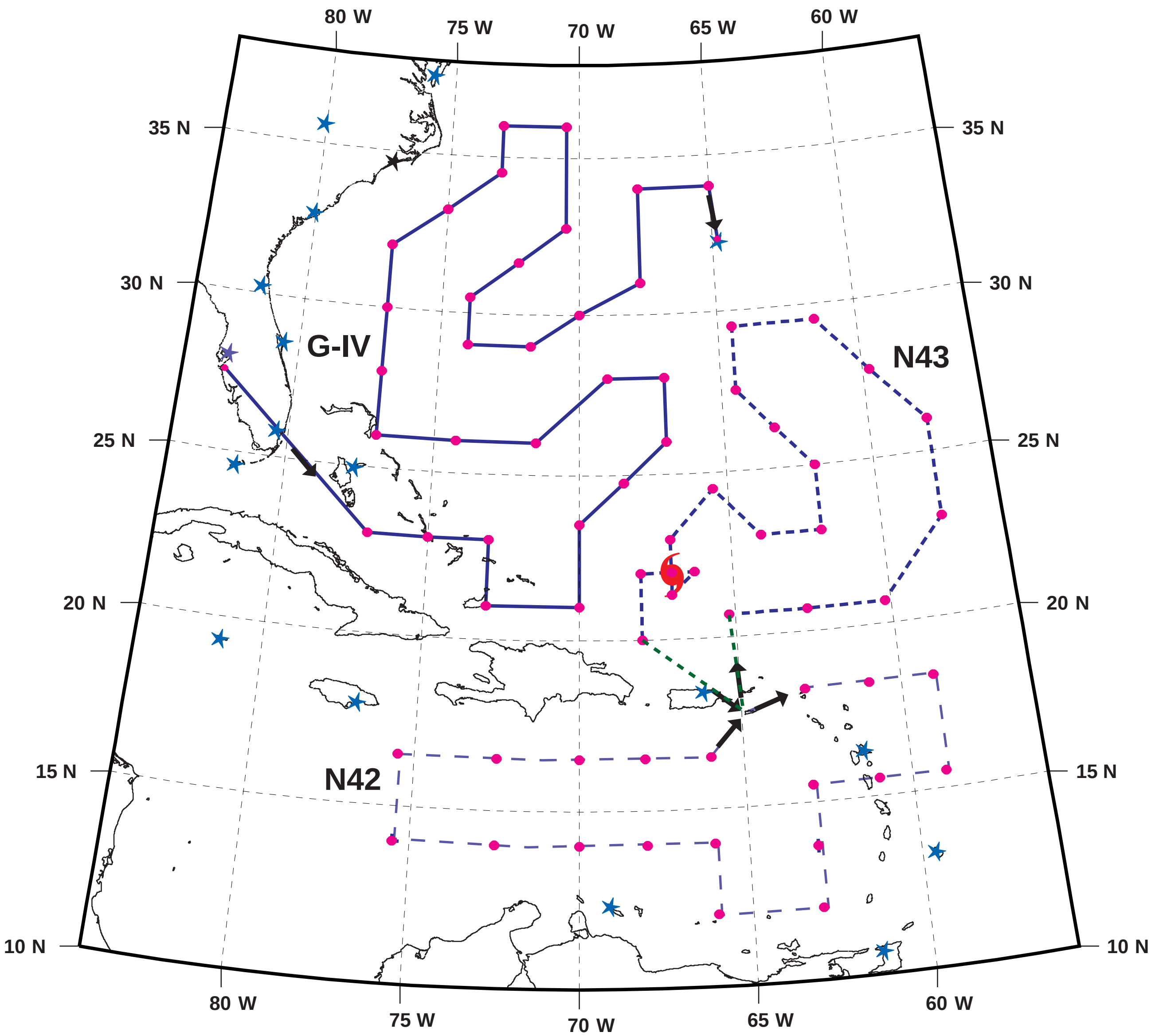


Fig. 1. Sample Environmental Patterns

• Note 1.	During the ferry to the **IP**, the WP-3D 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 2.	During the ferry to the **IP**, The G-IV should climb to the 41,000 ft (200 mb) as soon as possible and climb as feasible to maintain the highest altitude for the duration of the pattern.

HURRICANE SYNOPTIC FLOW EXPERIMENT

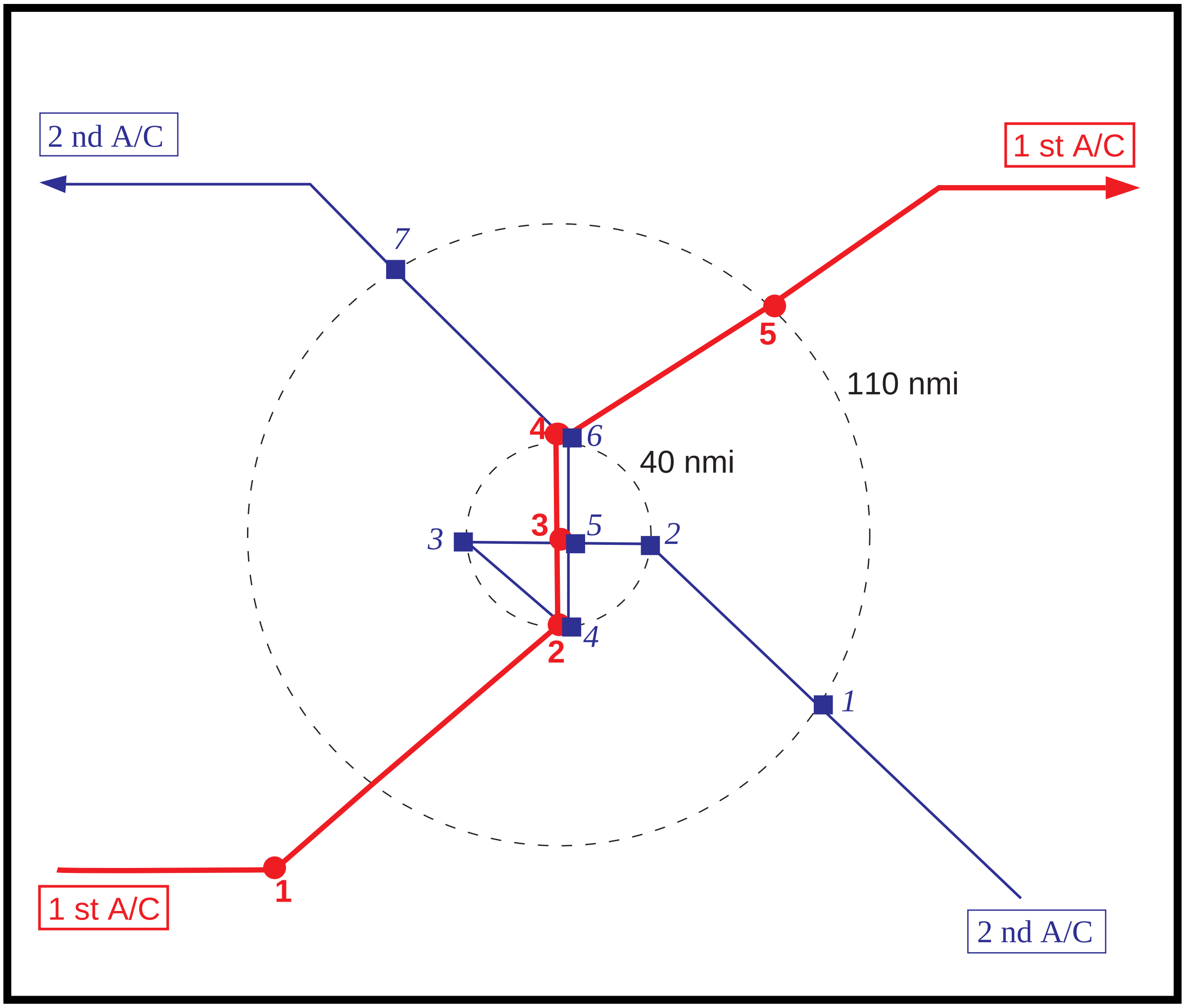


Fig. 2 In-Storm Patterns

• 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

HURRICANE SYNOPTIC FLOW EXPERIMENT

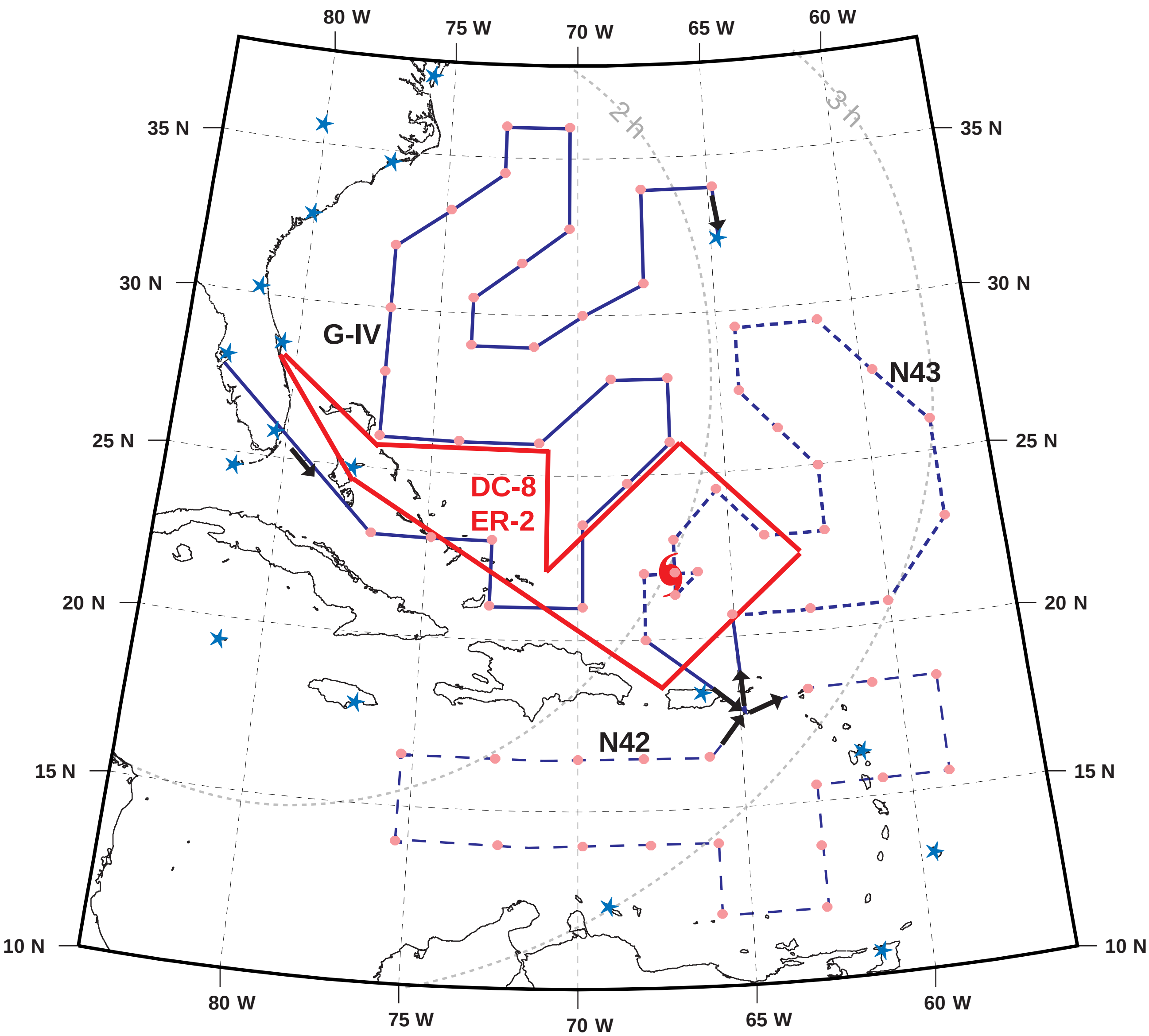


Fig. 3. DC-8 and ER-2 Sample Surveillance Pattern

- Note 1. Aircraft should begin pattern at approximately the same time as the two WP-3D aircraft, but precise coordination is not required.
- Note 2. Each aircraft begins the pattern with an over flight of the ground test facility on Andros Island.
- Note 3. DC-8 should attain the 200-mb level (about 41,000 ft [FL 410) as early in the mission as possible and climb as feasible to maintain the highest altitude for the duration of the pattern.
- Note 4. Dropwindsondes and the downward-pointing lasers may pose a hazard to the WP-3D or WC-130 aircraft. Hence, positive communication with these aircraft must be obtained before the laser is operated or sondes released.
- Note 5. If a G-IV surveillance mission is conducted simultaneously care must be taken by the DC-8 crew to coordinate with the operational G-IV mission. G-IV dropwindsondes may pose a hazard to the DC-8 aircraft. Therefore, the DC-8 mission should avoid conflicts with the operational requirements.

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. 4). 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.

A CAMEX-3 objective is to obtain wind and precipitation measurements in the inner core of the storm using the remote sensors on the DC-8 and ER-2 (Appendix B). This mission is best when coordinated with another multi-plane experiment, to provide ground truth for the remote sensing instruments. A sample inner core mission is shown in Fig. 5. The DC-8 aircraft and the ER-2 will take off a half to one hour after the two WP-3D aircraft in order to coordinate the in-storm patterns. Subject to safety and operational constraints, the DC-8 will climb to the 250-mb level (about FL 370) or above and the ER-2 climbs to 65,000 ft. Both aircraft fly over the ground test facility on Andros Island on their way to the storm. The WP-3D lead scientist will pass storm position, storm motion, and a recommended IP to the DC-8 lead scientist. The nominal leg length will be 200-300 nmi (370-550 km), but the size of the pattern will be adjusted to make the legs as long as possible given the available aircraft range. The inner core pattern (Fig. 5b), designed to provide detailed observations of the eye and eyewall structure, is executed at the discretion of the DC-8 lead scientist in coordination with the WP-3D lead scientist.

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. 6). 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. 7). 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. 8). One of the two WP-3D aircraft would fly through the center and collect Doppler and reflectivity data.

XCDX EXPERIMENT

Vortex Option

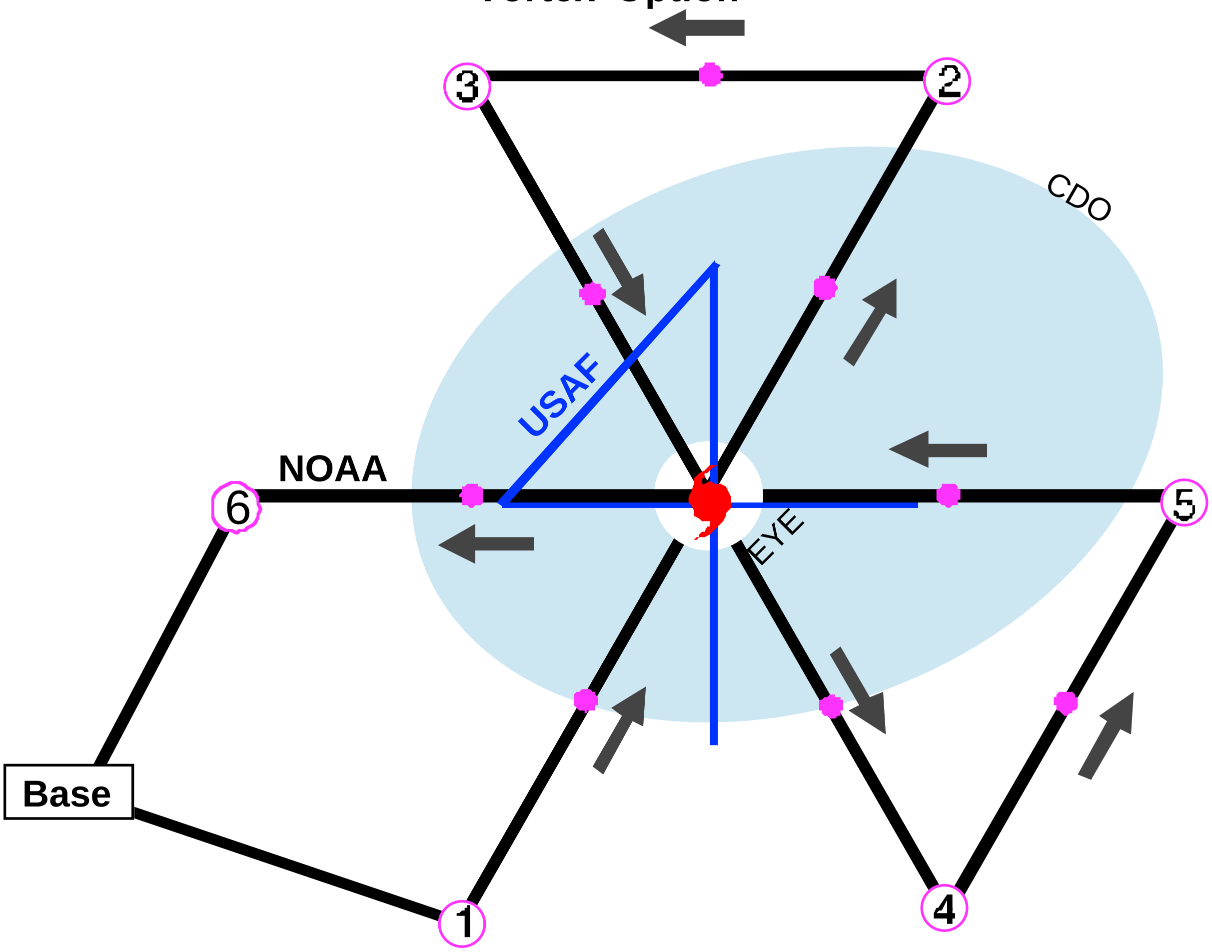


Fig. 4. WP-3D pattern

• 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

Vortex Option

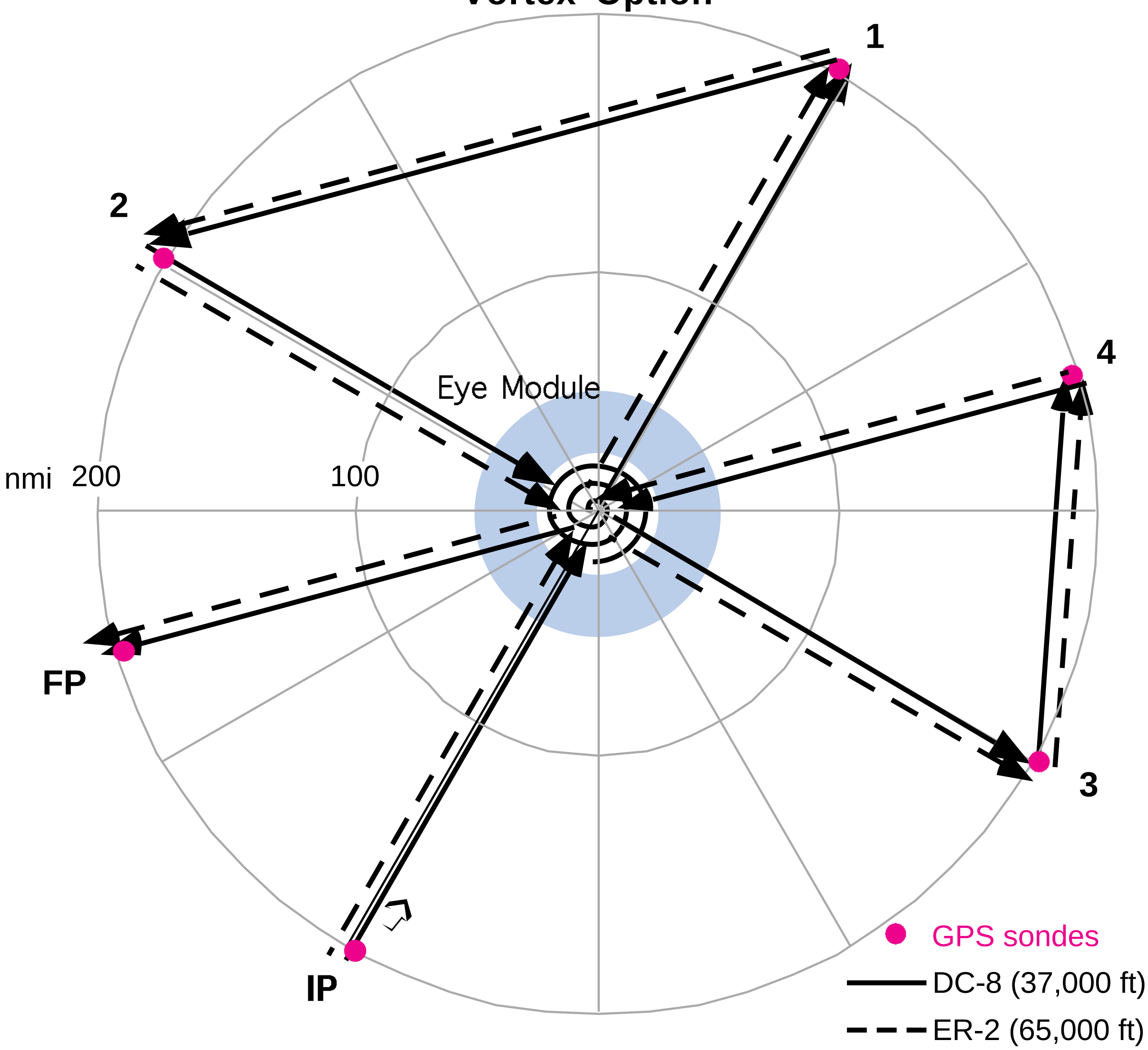


Fig. 5. (a) DC-8 and ER-2 Sample Pattern

- Note 1. Aircraft should begin pattern at approximately the same time as the WP-3D's, but precise coordination is not required.
- Note 2. Aircraft should not deviate from pattern to find the wind center in the eye.
- Note 3. The pattern may be entered at any compass heading, and entry azimuth should be at least 30° downwind of the entry azimuth of the WP-3D or WC-130 aircraft.
- Note 4. The DC-8 should attain the 200-mb level (about 41,000 ft [FL 410) as early in the mission as possible and then maintain this altitude for the duration of the pattern.
- Note 5. If desired dropwindsondes should be released at IP and turn points.
- Note 6. Dropwindsondes and the downward-pointing lasers may pose a hazard to the WP-3D or WC-130 aircraft. Therefore positive communication with these aircraft must be obtained before these sondes are released.
- Note 7. Total pattern length is approximately 1800 nmi (3330 km).

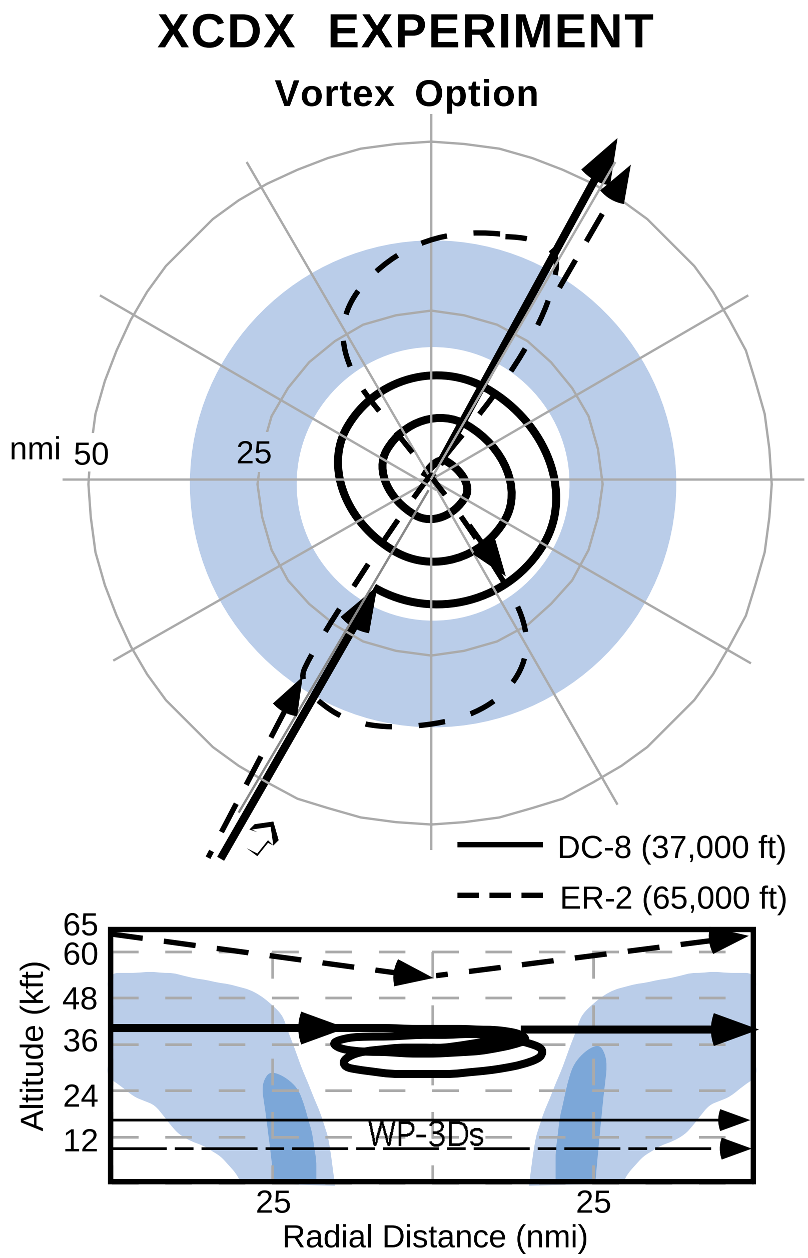


Fig. 5. (b) DC-8 and ER-2 Eyewall Module

• Note 1.	Aircraft should begin pattern at approximately the same time as one of the WP-3D's begins circling the outside of the eyewall, but does not have to be precisely coordinated.
• Note 2.	The DC-8 spiral descent begins at flight level in the eye and ends at 28,000 ft, followed by a spiral ascent to 37,000 ft before leaving the eye.
• Note 3.	The ER-2 performs a figure-8 over the eyewall region with dips to 52,000 ft in the eye if the pilot deems it safe.
• Note 4.	Pattern should take no more than 30 min.

XCDX EXPERIMENT

Vortex Option

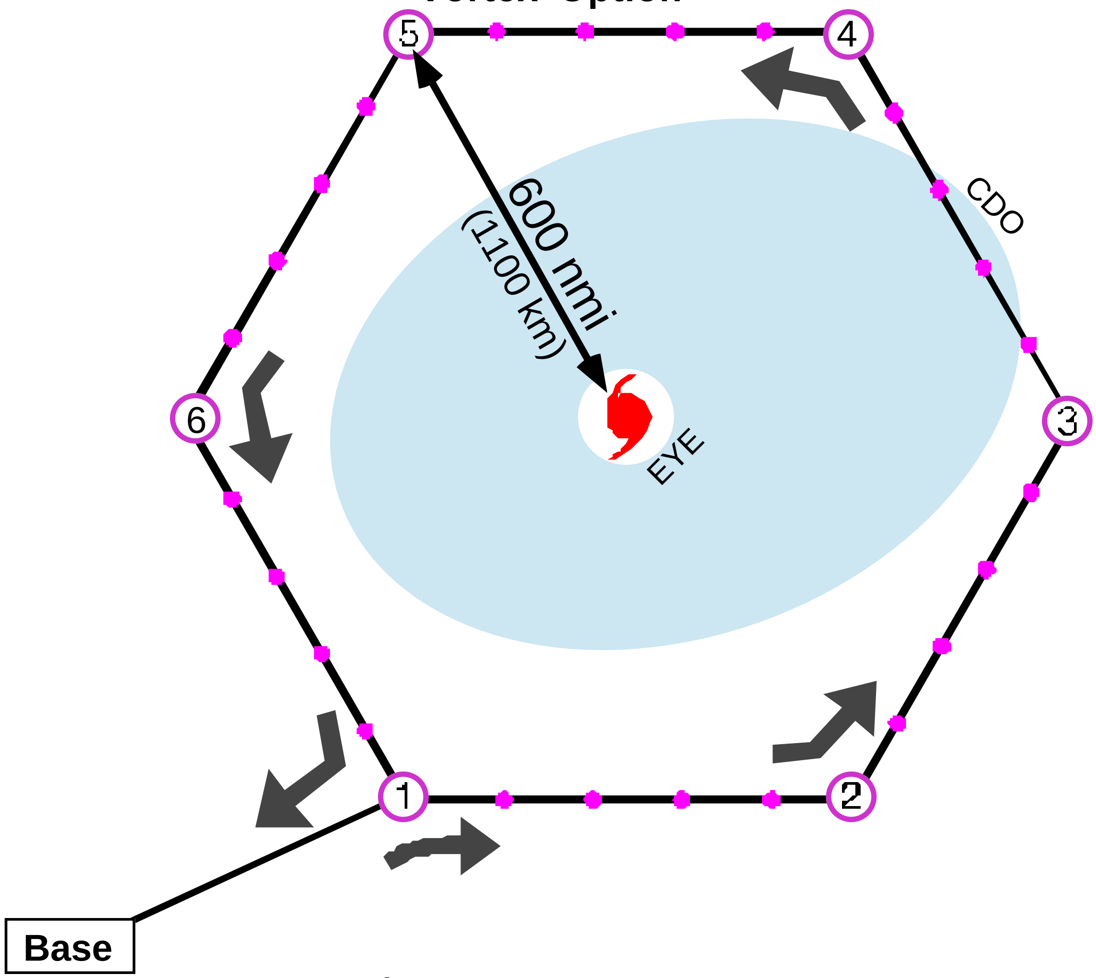


Fig. 6. G-IV pattern

• 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

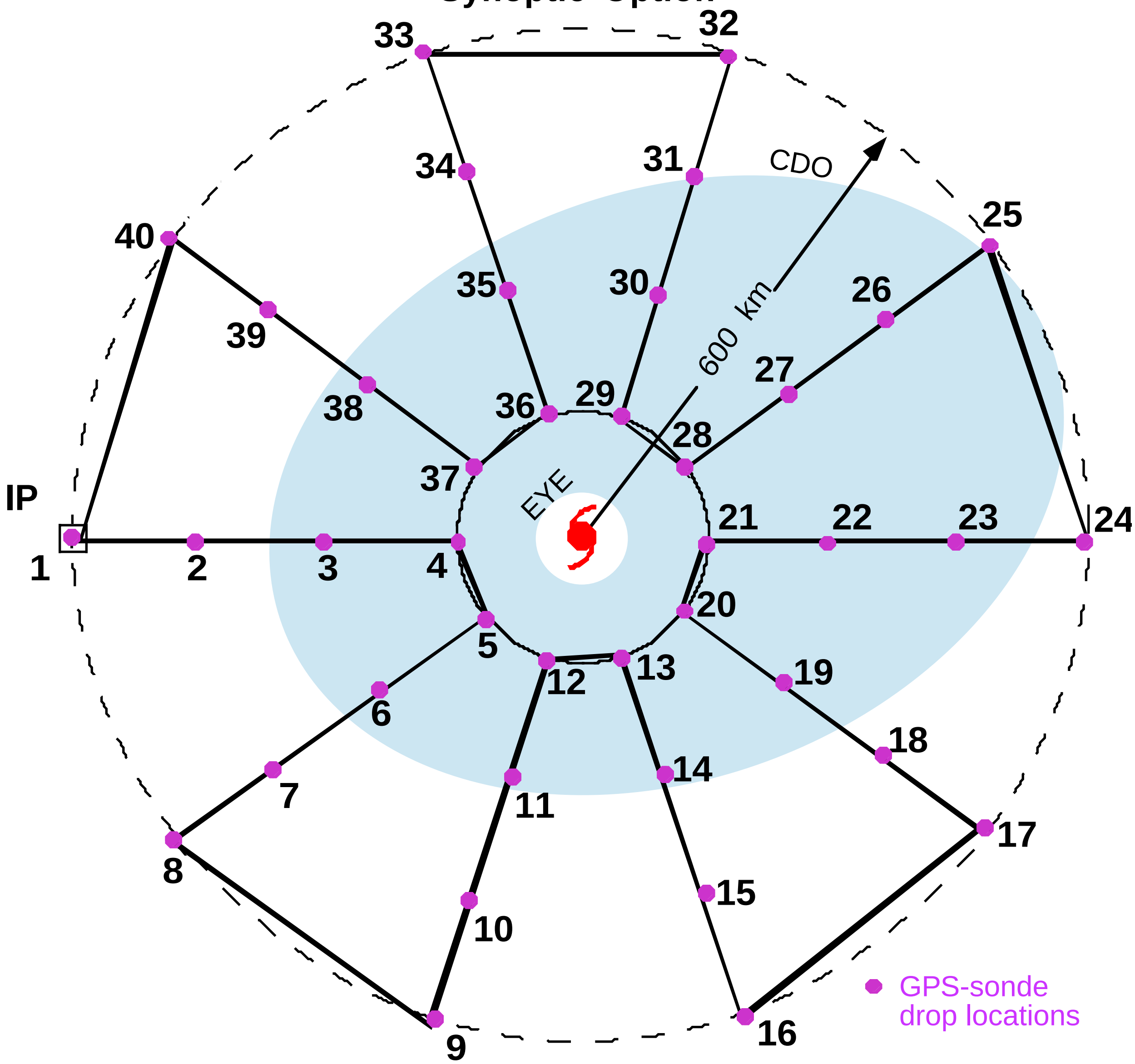


Fig. 7. **G-IV pattern**

• 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

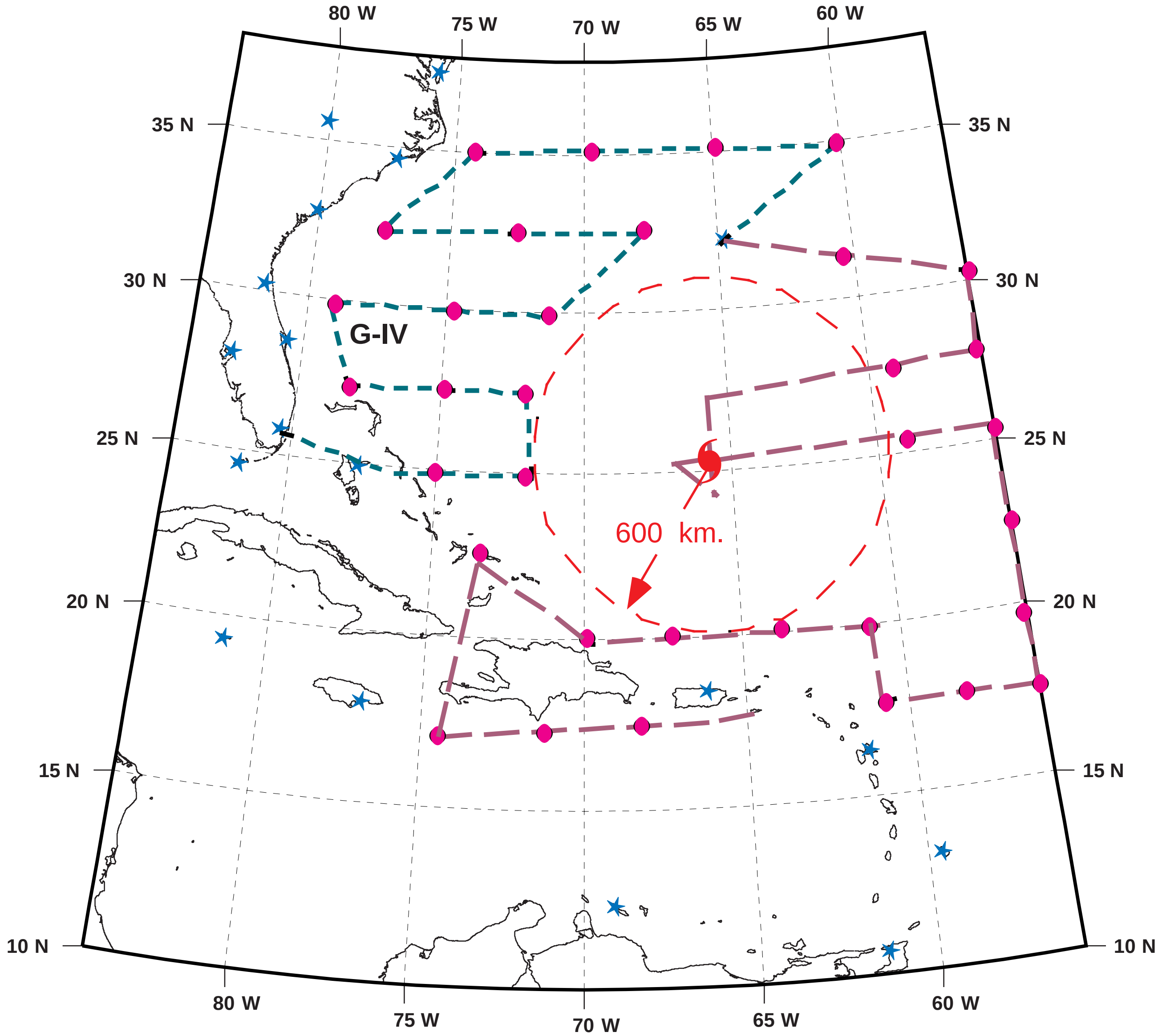


Fig. 8. Sample WP-3D pattern

• 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 1998, 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. 9. 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. 9, 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. 10. 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 (Fig. 10d). This would occur just after the coordinated figure-4 pattern (i.e., immediately following nav points **5**, **13**, or **21** [Fig. 10]). 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. 10d).

A CAMEX-3 objective is to obtain wind and precipitation measurements in the inner core of the storm using the remote sensors on the DC-8 and ER-2 (Appendix B). This mission is best when coordinated with another multi-plane experiment, to provide ground truth for the remote sensing instruments. These types of observations, together with dropwindsondes from the DC-8, could greatly enhance the VME Experiment. With that in mind, HRD will provide GPS-sondes for the DC-8 to execute a VME version of their inner core pattern. A sample inner core mission is shown in Fig. 11. The DC-8 aircraft and the ER-2 will take off a half to one hour after the two WP-3D aircraft in order to coordinate the in-storm patterns. Subject to safety and operational constraints, the DC-8 will climb to the 200-mb level (about FL 410) or above and the ER-2 climbs to 65,000 ft. Both aircraft fly over the ground test facility on Andros Island on their way to the storm. The WP-3D lead scientist will pass storm position, storm motion, and a recommended IP to the DC-8 lead scientist. The *most important aspect of the pattern is the azimuthal and radial position of each sonde drop relative to those of the upper WP-3D aircraft.* The inner core pattern (Fig. 5b), designed to provide detailed observations of the eye and eyewall structure, can be executed at the discretion of the DC-8 lead scientist in coordination with the WP-3D lead scientist, as long as the dropwindsonde portion of the mission is not compromised.

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

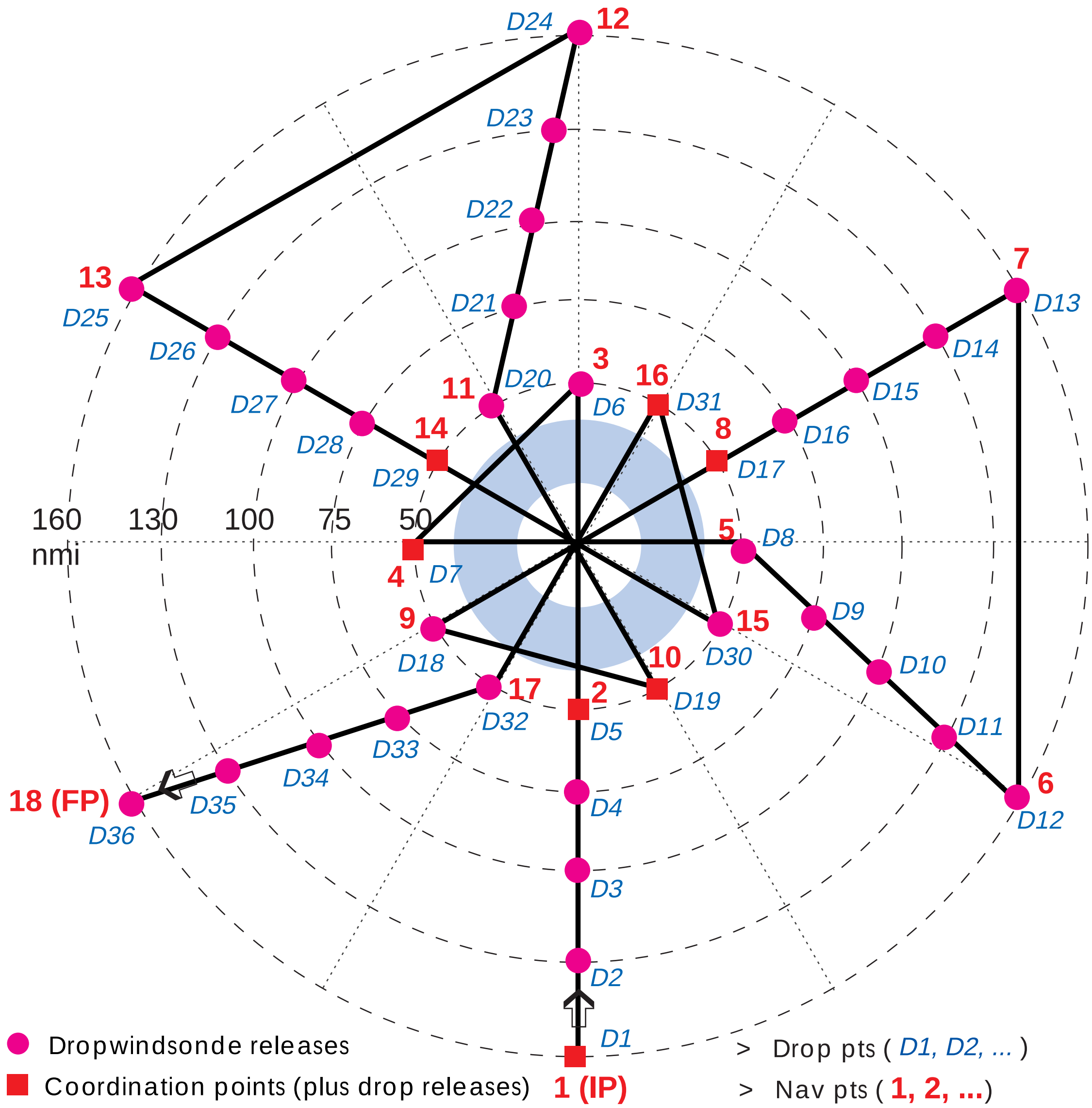


Fig. 9. Sample Upper Aircraft Flight Pattern

• 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

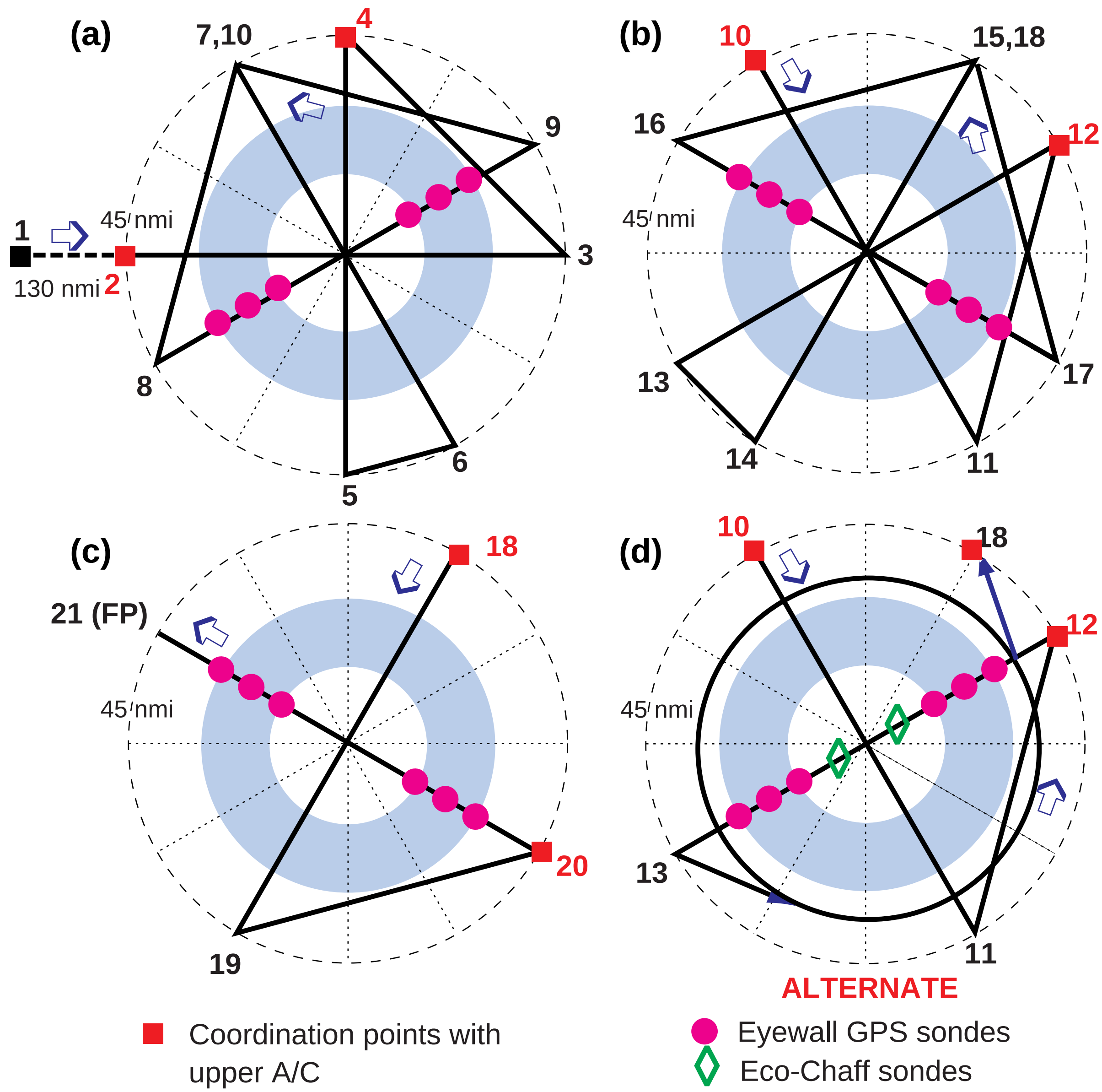


Fig. 10. Sample Lower Aircraft Flight Pattern

• 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). Eyewall drops may be required at the discretion of the lead mission scientist. As many as 3 drops per penetration, with spacing of 10-30 km, may be requested.
• 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.

VORTEX MOTION AND EVOLUTION EXPERIMENT

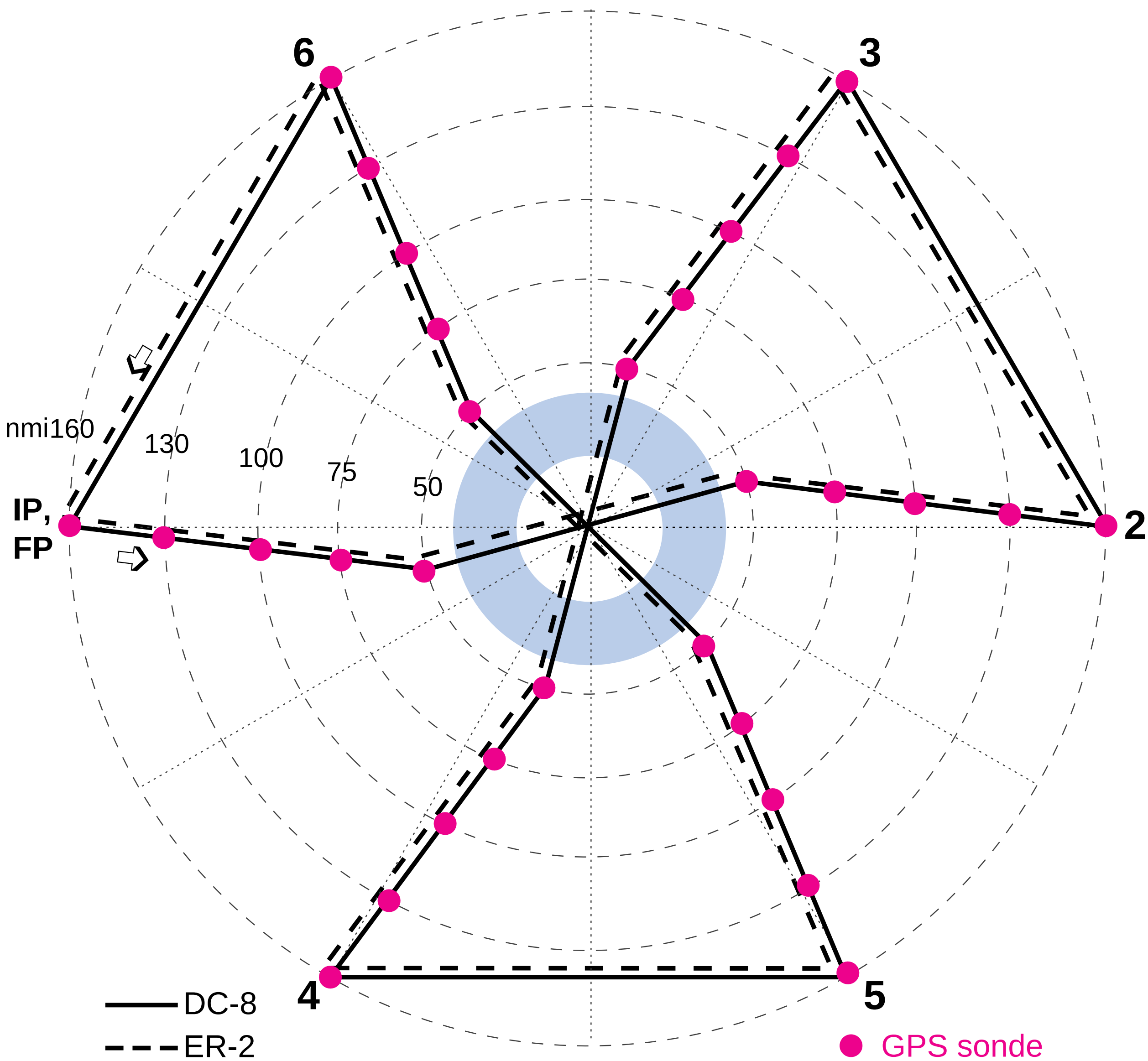


Fig. 11. Sample DC-8 and ER-2 Flight Pattern

- Note 1. Aircraft should begin pattern at approximately the same time as the two WP-3D's, but precise coordination is not required.
- Note 2. Aircraft should not deviate from pattern to find the wind center in the eye.
- Note 3. The pattern may be entered at any compass heading, but entry azimuth should be 90° upwind of that for the upper WP-3D aircraft.
- Note 4. DC-8 should attain the 200-mb level (about 41,000 ft [FL 410) as early in the mission as possible and climb as possible to maintain the highest altitude for the duration of the pattern.
- Note 5. Dropwindsondes may pose a hazard to the WP-3D or WC-130 aircraft. Therefore, positive communication with these aircraft must be obtained before sondes are released.
- Note 6. Total pattern length is approximately 1600 nmi (2960 km).

12. Tropical Cyclogenesis Experiment

Program Significance: The importance of multiscale processes during tropical cyclogenesis and cyclolysis have been demonstrated by composite of operational analyses and case studies of Atlantic genesis (e.g. Dolly of 1996) and lysis events (e.g. Tropical Depression #5 of 1997). Western and eastern Atlantic composites created using archived NHC ATOLL/200 mb analyses and best track data for 1975-1993 have shown the dynamical importance of ascent forced through cyclonic vorticity advection (CVA) by the thermal wind in the incipient storm environment. During genesis this CVA and forced ascent is generally found equatorward of a 200 mb zonally oriented ridge axis in association with an easterly jet over the eastern Atlantic Ocean and downstream (upstream) of a 200 mb trough (ridge) over the western Atlantic Ocean. In both composites the ATOLL disturbance is located beneath an area of CVA and near a minimum in vertical wind shear (200 mb-ATOLL). Flow decomposition techniques reveal the importance of large-scale deformation processes at both the 200 mb and ATOLL levels and indicate that both developing disturbances are found downstream of a southeasterly jet along the equatorward side of a ridge axis. Together, results from the flow decomposition diagnostics and compositing depict an environment favorable for persistent deep, moist convection over the ATOLL-level disturbance.

Tropical cyclogenesis can be viewed as a rapid increase of low- and mid-level cyclonic vorticity. Equivalently, tropical cyclone intensity change can be defined by changes in low- and mid-level vorticity. A knowledge of the processes that play a significant role in genesis might also advance our understanding of tropical cyclone intensity change. A better understanding of the processes that lead to an increase in low- and mid-level cyclonic vorticity will allow NHC to better monitor and forecast tropical cyclogenesis and changes in tropical cyclone intensity, especially those events that threaten coastlines. Data obtained by aircraft investigating potential genesis events will positively impact operations and research. The ingestion of this data into the NCEP model analysis and initialization schemes should permit an improvement in NCEP model forecast performance based upon a better representation of the mesoscale and synoptic-scale structure in the vicinity of the incipient disturbance. Likewise, the aircraft data will play a crucial role in future research projects that focus on tropical cyclogenesis and tropical cyclone intensity change.

Composites created for regions characteristic of early/late season genesis events (the Bahamas) and mid-season genesis events (Cape Verde) illustrate the features that play a significant role in north Atlantic genesis. In the Bahamas region a 200 mb trough-ridge couplet that straddles the developing ATOLL disturbance is crucial in producing CVA over the disturbance. In contrast, in the Cape Verde region only a 200 mb zonally oriented ridge is associated with the production of CVA over the ATOLL disturbance. However, the ATOLL disturbance structure is similar in both the Bahamas and Cape Verde genesis composites. The results uncovered by the composite studies indicate that it will be necessary to sample the upper-tropospheric wind, temperature, and moisture fields within ~1500 km from the disturbance if genesis is to be more fully understood and better forecast. Given the importance of upper troposphere features during genesis, it is critical that the G-IV be used during data-gathering missions with the two WP-3D aircraft.

The proposed experiment to study tropical cyclogenesis is designed to investigate how a synoptic-scale low-to-mid tropospheric cyclonic vorticity maximum is transformed into a tropical cyclone. Results obtained from a WP-3D aircraft investigation of Dolly (1996) indicate its genesis was strongly influenced by processes on different scales. Mesoscale Convective System (MCS) organization and persistence in association with an easterly wave over the Caribbean was strongly modulated by the synoptic-scale flow. Once persistent organized deep moist convection was established, mesoscale processes were then able to aid in the formation of an eye-like feature. Crucial to understanding the formation of this eye-like feature is a determination of the source of low level cyclonic vorticity. In order to observe this low level vorticity growth it will be necessary to obtain data over an extended uninterrupted time period within the developing disturbance. This will require that WP-3D aircraft fly staggered missions. In addition, it would be beneficial to double-crew the G-IV so that simultaneous large scale environmental-flow changes could be observed during the growth of low-level vorticity within the disturbance.

The importance of this experiment has implications beyond the better understanding and forecasting of tropical cyclogenesis and low-to-mid level cyclonic vorticity growth. For example, the proposed experiment should yield useful insight into the structure, growth and ultimately the predictability of the systems responsible for the most tropical precipitation. Investigation of systems that fail to complete the genesis process should also result in a better understanding and prediction of easterly disturbances in general so that distinction can be better made between developing and non-developing tropical disturbances.

Objectives:

- Determine how low-level vortices associated with organized mesoscale convective systems are produced.
- Determine what distinguishes developing from non-developing low-level vortices.
- Determine the dynamical linkage between synoptic-scale forcing and processes that lead to spin-up of the low-level mesoscale vortex.
- Determine the role of deep moist convection in the upward growth of low-level vortices and the downward growth of mid-level vortices.
- Determine how preexisting mid- and low-level mesoscale vortices interact during genesis.
- Determine the dynamical and thermodynamical linkage between low-level mesoscale vortex spin-up and the larger scale environmental relative humidity.
- Determine the relative importance of external influences and internal processes during genesis.

Mission Description: This experiment may be executed with aircraft from NOAA alone, or NOAA in cooperation with NASA and/or the USAF flying into pre-genesis and incipient tropical disturbances over the Atlantic Ocean, Caribbean Sea, Gulf of Mexico, and tropical eastern North Pacific Ocean. The primary mission will require two WP-3Ds flying back-to-back with the G-IV aircraft flying a coordinated pattern. The two WP-3Ds will fly low- and mid-level mesoscale patterns in close proximity to any suspected low-level vortices while the G-IV simultaneously flies at upper levels (200-300 mb) and collects observations to a distance of ~1500 km from the center of the disturbance. If available, the USAF WC-130 and NASA DC-8 aircraft can be used to significantly enhance observations at all levels.

The main aircraft for the low- and mid-level flights will be the two WP-3Ds. Doppler radar observations, GPS-sondes, scatterometer, and flight level observations obtained during these flights will help locate low- and mid-level vortices and help document their structures and life cycles. Crucial to a complete understanding of the genesis process is the collection of observations with high temporal and spatial resolution. A primary aspect of this experiment will be to observe the complete life cycle and interaction of low- and mid-level vortices and understand how these vortices are influenced by the diurnal cycle of convection. Staggered missions with the two WP-3D aircraft will begin with the first aircraft flying a figure-4 pattern at 700-500 mb (10,000-18,000 ft or 3.0-5.5 km; Fig. 12). Persistent areas of deep convection and/or low-level rotation identified with satellite imagery will be used to center the flight plan. Leg lengths will be 325-430 nmi (600-800 km), and the pattern will be centered approximately on the deep convection and/or incipient vortex. The primary purpose of these aircraft missions will be to collect FAST Doppler radar and GPS-sonde data in the area of deep convection in order to map the evolution of the three-dimensional wind and thermodynamic structure of the deep convection and incipient vortex. Once a low-level vortex is identified flight legs will be significantly reduced in length [100-135 nmi (180-250 km)] to allow for the collection of data with high temporal and spatial resolution in the vicinity of the vortex (Fig. 13). If no low-level vortex is apparent the low-level grid pattern (Fig. 14) should be employed.

If available, the G-IV will be most beneficial flying a synoptic-scale pattern. It will fly at maximum altitude observing the upper and lower troposphere with GPS-sondes in the pre-genesis and incipient tropical disturbance environment. A potential genesis event occurring in conjunction with primarily an upper tropospheric anticyclone will require a flight pattern similar to that given in Fig. 15a. The aircraft will dispense 20-25 GPS-sondes mostly on the poleward side of the incipient disturbance during the flight to help define wind, temperature and moisture patterns near the ridge axis. Should a potential genesis event occur in association with an upper-tropospheric trough-ridge couplet a flight pattern similar to that shown in Fig. 15b will be required. This flight pattern will collect observations in the vicinity of both the trough and ridge with upwards of 20-25 GPS-sondes. These flight patterns are designed to define those regions where large-scale forcing for ascent exists and persistent deep convection is favored.

An enhancement of the data collected during genesis by the three NOAA aircraft may be accomplished by adding observations from investigative USAF WC-130 and/or NASA DC-8 and ER-2 aircraft. Should a USAF WC-130 aircraft be available it would be requested to fly at maximum altitude dispensing GPS-sondes in the southern and eastern quadrants of the incipient disturbance. This aircraft would be requested to fly a saw-tooth pattern centered on asymptotes of confluence, convective inflow bands, and/or thermal boundaries within ~300 nmi (500 km) of the incipient disturbance. The NASA DC-8 and ER-2 aircraft would be requested to assist the G-IV in the collection of upper- and lower-tropospheric observations with GPS-sondes to a radial distance of ~900 nmi (1500 km) from the incipient disturbance. Operation of these two aircraft will be staggered in a manner similar to the two WP-3Ds to allow nearly continuous sampling of the large-scale upper and lower troposphere in time.

The possible availability of multiple aircraft during this experiment leads to several different scenarios. A summary of the potential combinations of aircraft during genesis experiments follows:

- Option 1 (lesser experiment):

  The two core NOAA WP-3D aircraft alone will fly staggered figure-4 or grid patterns (Figs. 12-14) centered on the area of persistent deep convection and/or any low level vortex over a 2-4 day period.

- Option 2 (primary experiment):

  Option 1 augmented with large-scale upper- and lower-tropospheric observations obtained by the G-IV aircraft flying patterns similar to those given in Figs. 15.

- Option 3 (optimal experiments):

  A) Option 2 with USAF WC-130 flying a standard reconnaissance mission.

  B) Option 2 with USAF WC-130 flying a targeted mission to sample asymptotes of confluence, convective inflow bands, and/or thermal boundaries within ~300 nmi (500 km) of the incipient disturbance.

  C) Option 2 with NASA DC-8 and ER-2 aircraft flying staggered missions with the G-IV aircraft to collect quasi-continuous observations in the upper and lower troposphere within ~900 nmi (1500 km) of the disturbance.

  D) Option 3B with the NASA DC-8 and ER-2 aircraft flying staggered missions with the G-IV aircraft to collect quasi-continuous observations in the upper and lower troposphere within ~900 nmi (1500 km) of the disturbance.

TROPICAL CYCLOGENESIS EXPERIMENT

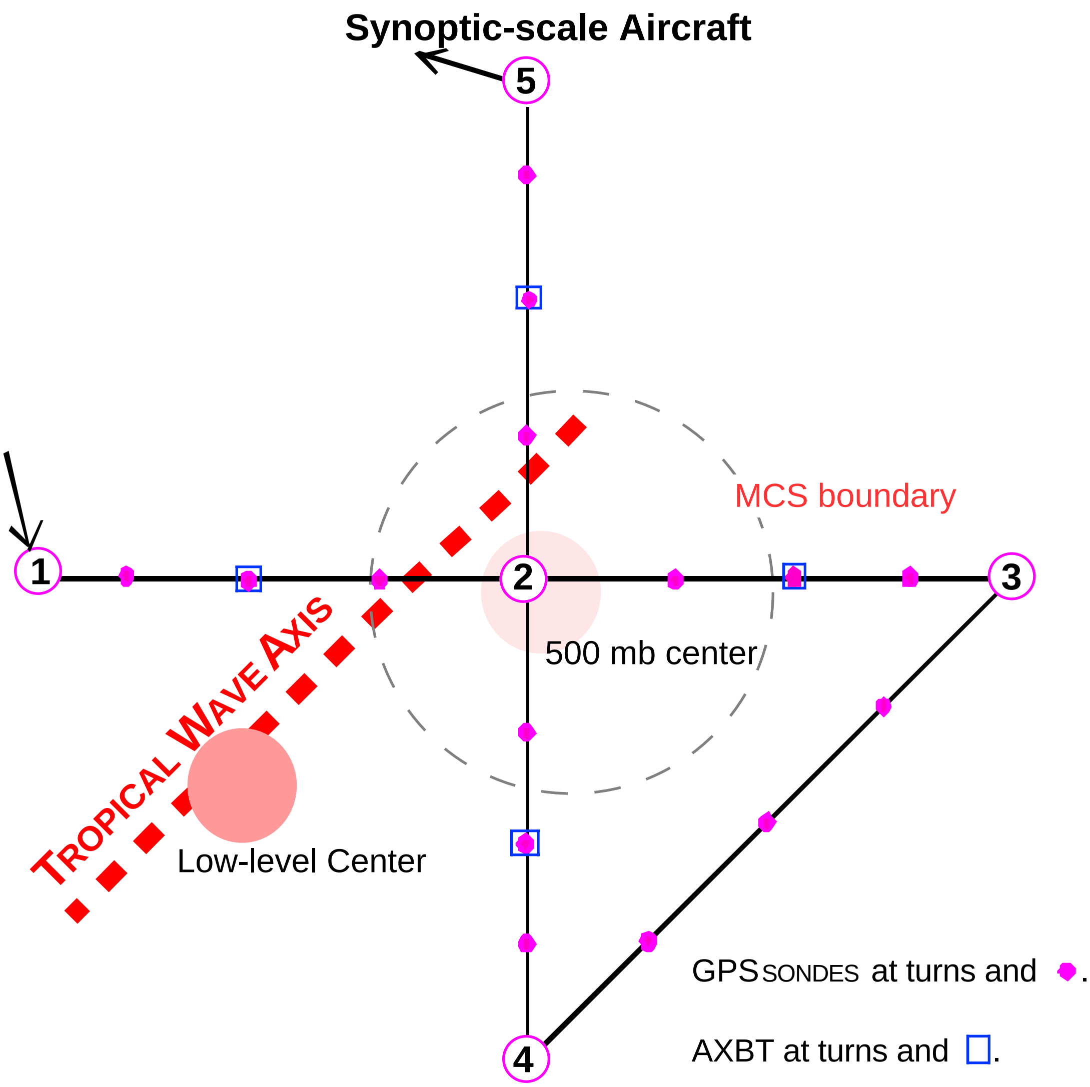


Fig. 12. Synoptic-scale Aircraft Flight Track

• 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

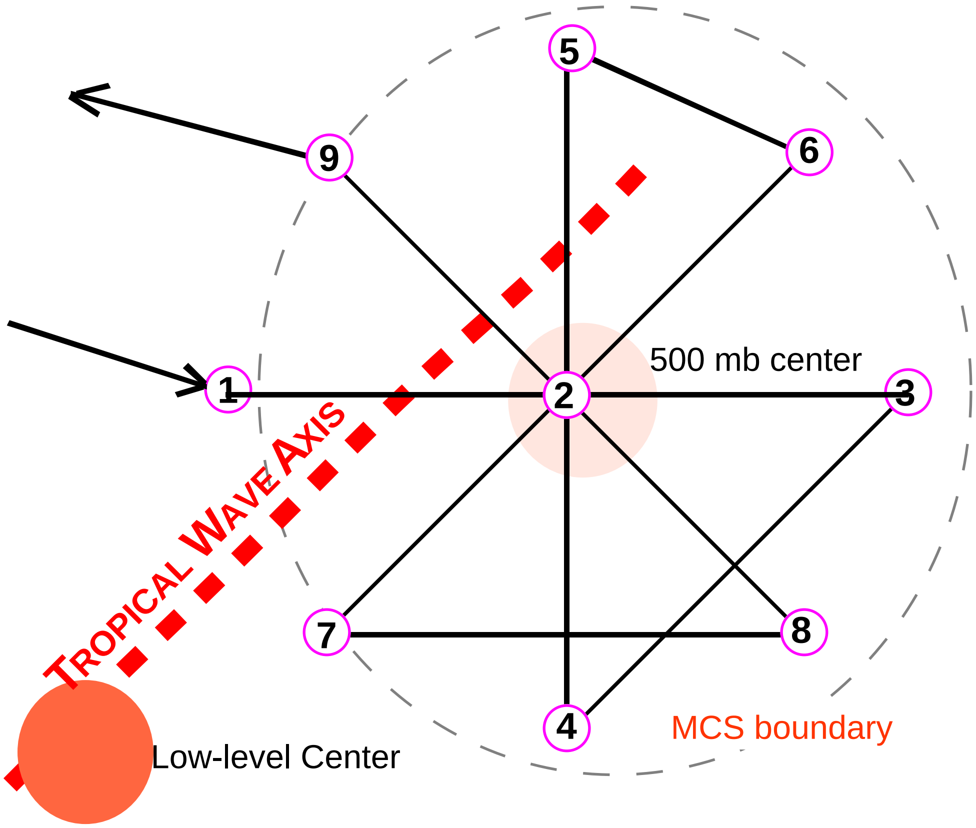


Fig. 13. Mesoscale Aircraft Flight Track

• 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

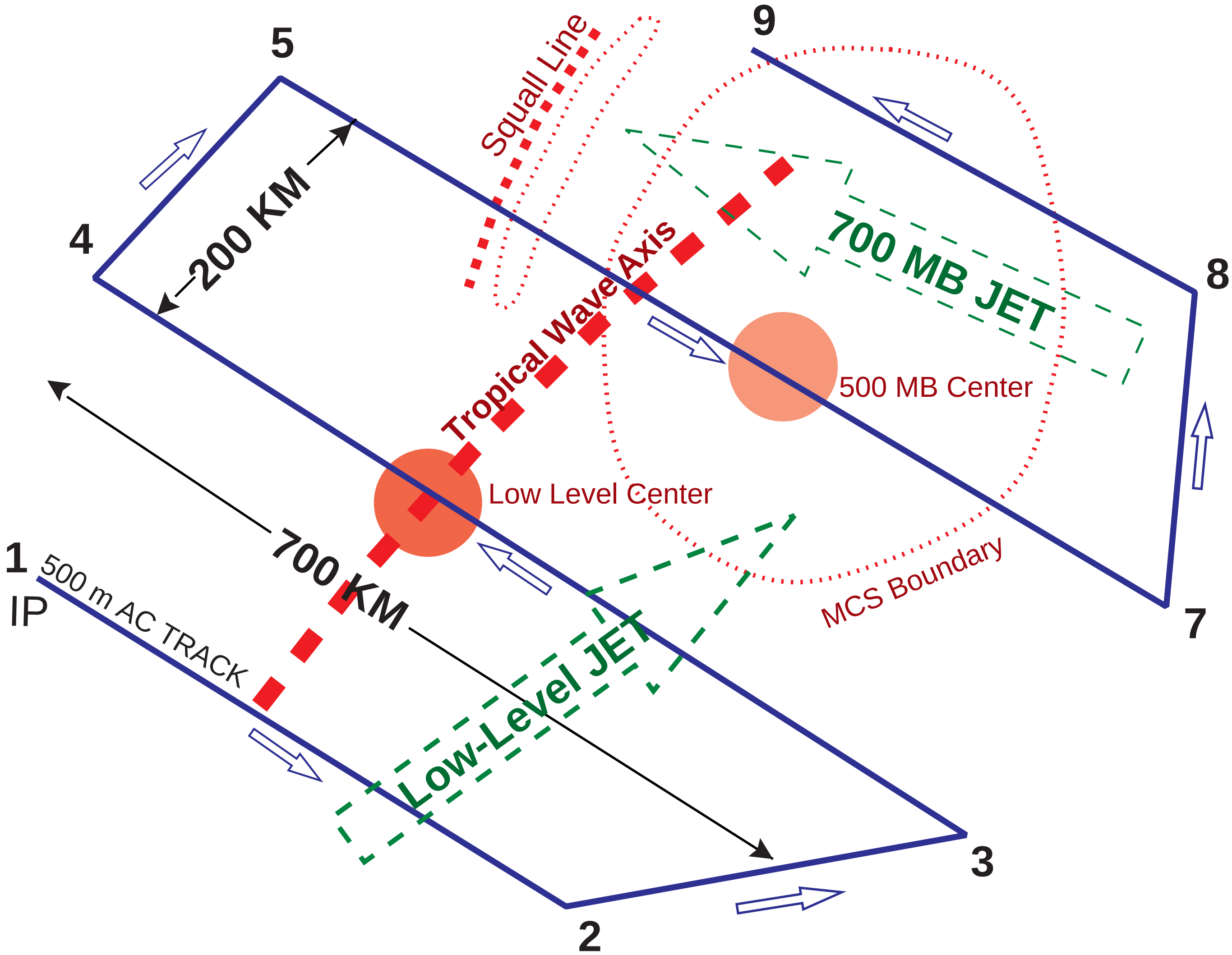


Fig. 14. Low-level Grid Flight Track

• 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.

TROPICAL CYCLOGENESIS EXPERIMENT

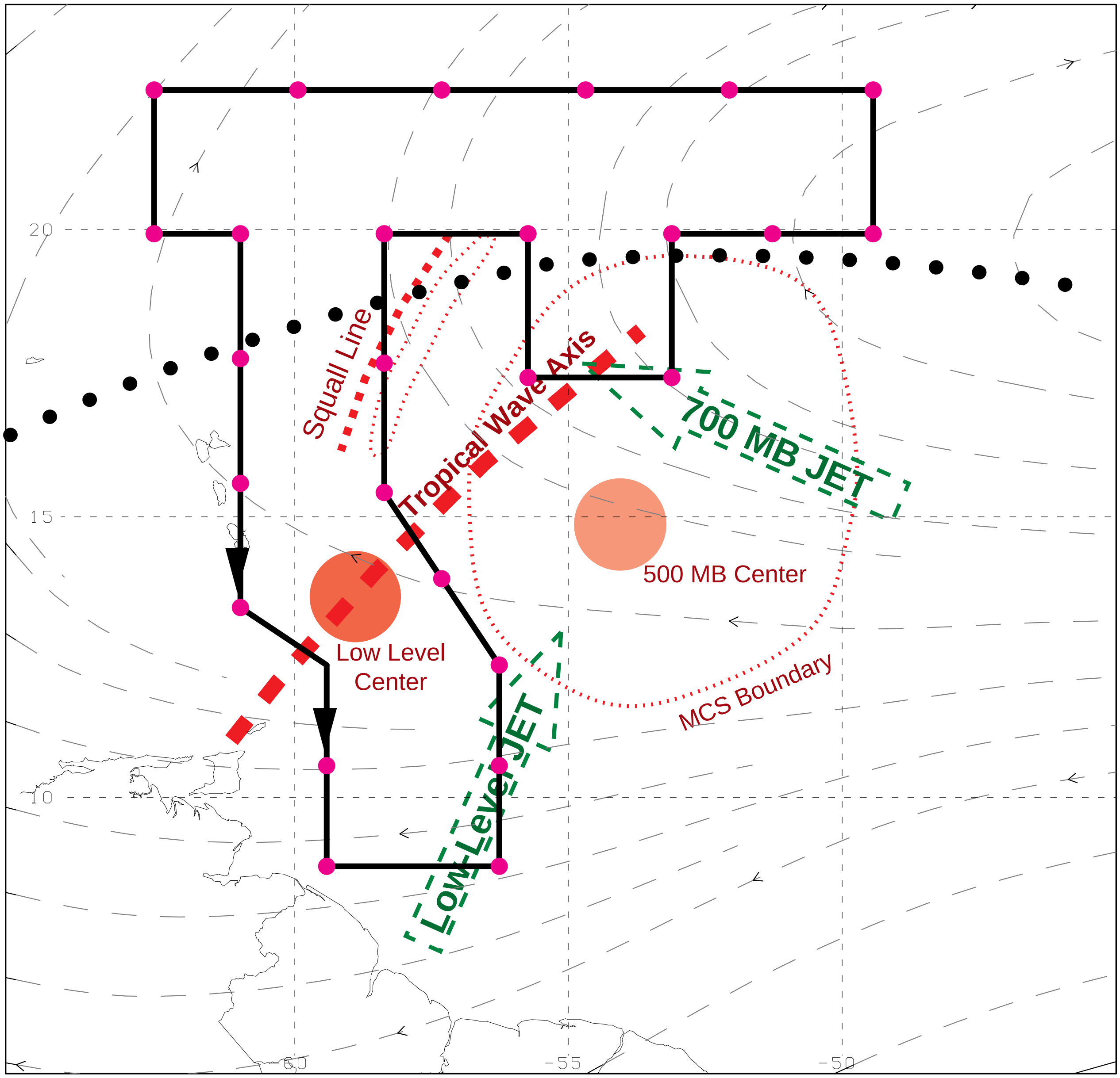


Fig. 15. (a) Cape Verde Region Sample G-IV Pattern

• Note 1.	During the ferry to the **IP**, The G-IV should climb to the 41,000 ft (200 mb) as soon as possible and climb as feasible to maintain the highest altitude for the duration of the pattern.
• Note 2.	Penetration of intense reflectivity or reflectivity gradient areas are optional.

TROPICAL CYCLOGENESIS EXPERIMENT

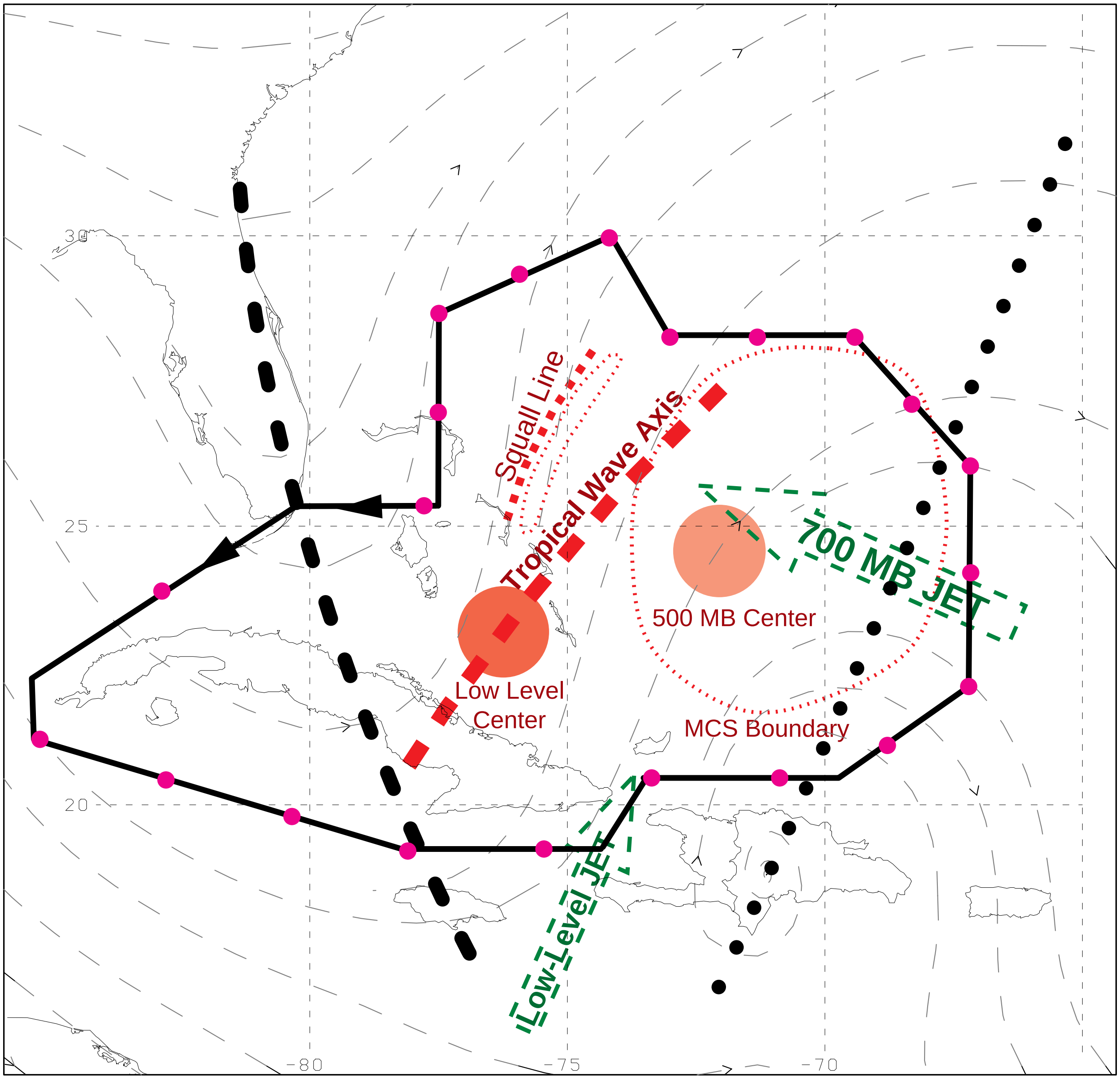


Fig. 15. (b) Bahamas Region Sample G-IV/DC-8 Pattern

• Note 1.	During the ferry to the **IP**, The G-IV or DC-8 should climb to the 41,000 ft (200 mb) as soon as possible and climb as feasible to maintain the highest altitude for the duration of the pattern.
• Note 2.	Penetration of intense reflectivity or reflectivity gradient areas are optional.

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. 16), yielding true Dual-Doppler coverage. Starting in 1997 the Atlantic and Gulf coasts were covered by a network of Doppler radars (WSR-88D) deployed by the National Weather Service (NWS), Department of Defense, and Federal Aviation Administration (Fig. 17). 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.

TROPICAL CYCLONE WINDFIELDS NEAR LANDFALL EXPERIMENT

Groundbased/Airborne Doppler Scanning Strategy

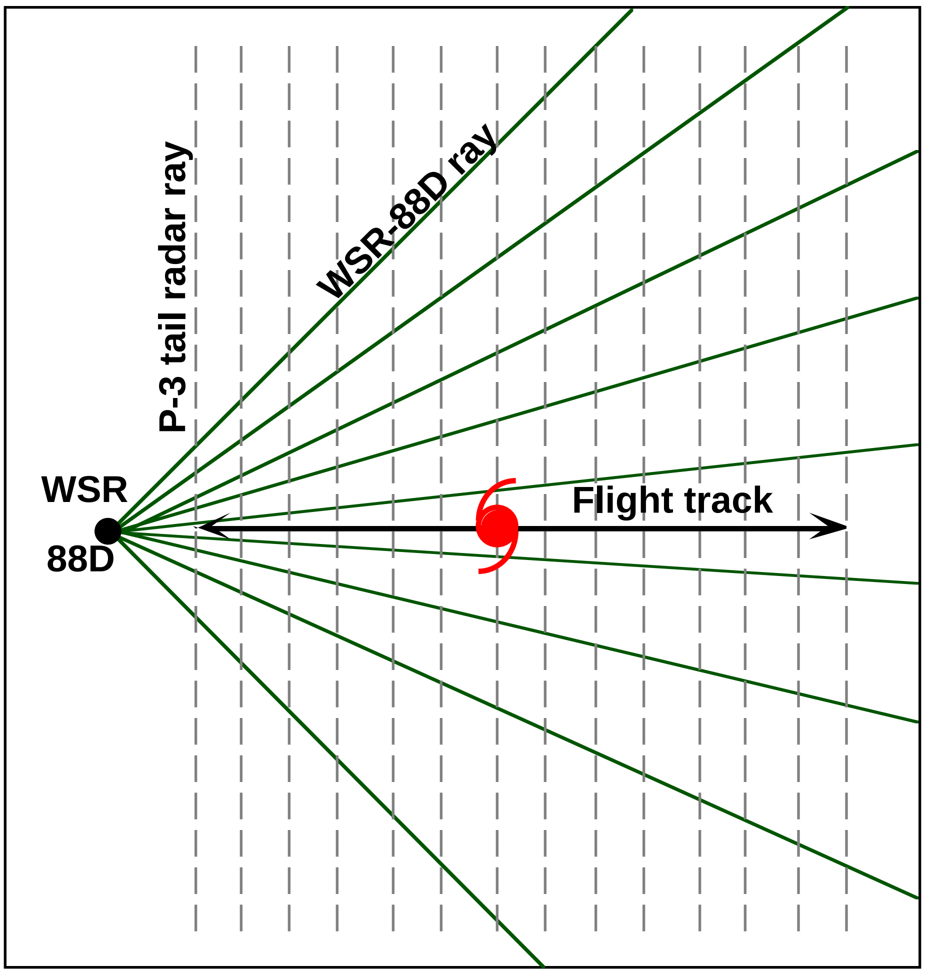


Fig. 16. Airborne Doppler Radar Flight Track

• 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

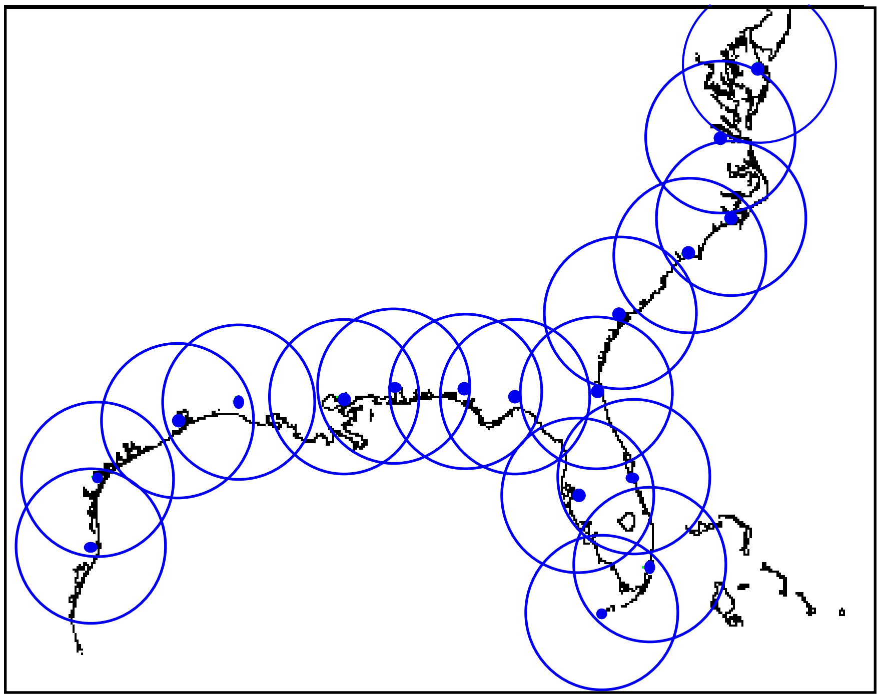


Fig. 17. The locations of the WSR–88D coastal radar sites. Range rings are at 125 nmi (230 km) radius.

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. If conditions permit, GPS-sondes will also be dropped in the eyewall in different quadrants of the hurricane, to add to the climatology of vertical wind profiles.

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 and NASA 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.
- Document changes in microphysics and rainfall characteristics in the storm during and after landfall.
- Obtain a remote sensing data base suitable for evaluation and improvement of satellite and ground validation rainfall estimation algorithms for landfalling TCs.

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 a WSR-88D, then the flight pattern should take advantage of buoys or C-MAN sites nearby. The aircraft descends at the initial point and begins a low-level figure-4 pattern, modifying the legs to fly over the buoys (Fig. 18). 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 or C-MAN sites.

If the timing is such that the storm is farther off the coast than desired for landfall, then the aircraft can execute the Rainband Thermodynamic Structure Module (Fig. 28) to map the thermodynamic structure of the in-flow. The flight pattern should overfly any buoy or C-MAN sites and if possible, include legs coordinated with a WSR-88D.

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. 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. 18). The aircraft then makes several passes through the eyewall (**A-B** in Fig. 18), 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.

A major CAMEX-3 objective is to obtain wind and precipitation measurements in the inner core of the storm as it makes landfall using the remote sensors on the DC-8 and ER-2 (Appendix B). These types of observations can greatly enhance the TC Wind fields at Landfall Experiment and can provide ground truth for the remote sensing instruments. The DC-8 aircraft and the ER-2 will take off 1/2 to 1- h after the WP-3D aircraft in order to coordinate the in-storm pattern (Fig. 5). Subject to safety and operational constraints, the DC-8 will climb to the 250-mb level (about FL 370) and the ER-2 climbs to 65,000 ft. Both aircraft fly over the ground test facility on Andros Island on their way to the storm. The WP-3D lead scientist will pass storm position, storm motion, and a recommended IP to the DC-8 lead scientist. Both aircraft will fly a pattern similar to Fig. 5a until the storm moves inland. Flight legs may be abbreviated at the coast at the discretion of the DC-8 crew. The DC-8 and ER-2 should fly along WSR-88D radials if dual-Doppler data are desired. The inner core pattern (Fig. 5b), designed to provide detailed observations of the eye and eyewall structure, can be executed in conjunction with the WP-3D repeated passes through the eyewall along **A-B** at the discretion of the DC-8 lead scientist in coordination with the WP-3D lead scientist.

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. 19). 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. 20). 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 with the WP-3D at 10,000 or 15,000 ft (3.0 or 4.5 km), the DC-8 at 37,000 ft (11 km), and the ER-2 at 67,000 ft (20 km) are feasible over land, the pattern shown in Figs. 20 and 21 would be flown. The storm can be followed inland as long as time and safety considerations permit. If possible the DC-8 and WP-3D should fly legs along WSR-88D radials with the ARMAR and tail Doppler radar in F/AST scanning mode.

TROPICAL CYCLONE WINDFIELDS NEAR LANDFALL EXPERIMENT

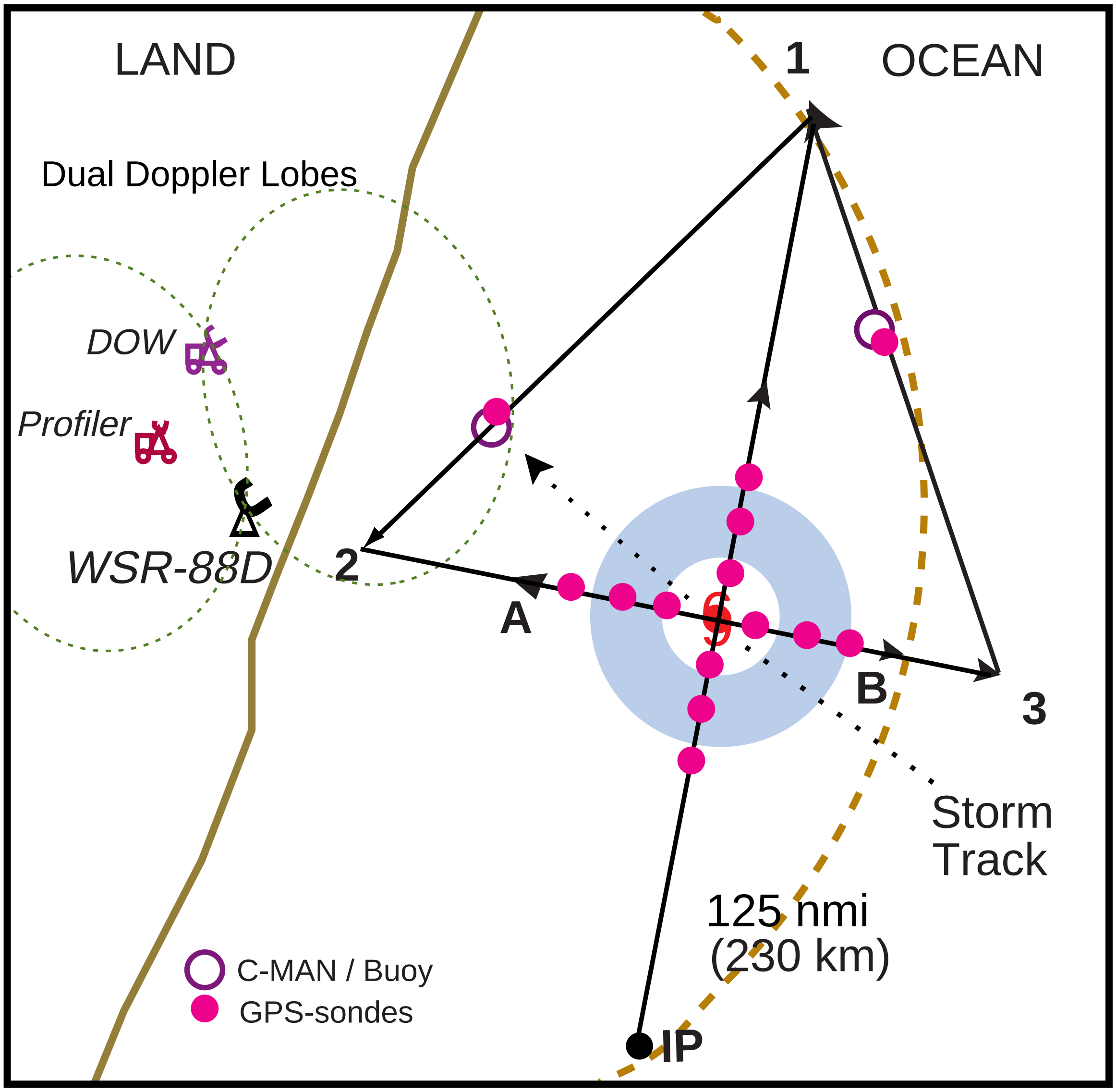


Fig. 18. **Flight track for the real-time module with over flights of moored buoys for a storm passing within range of a coastal WSR-88D.**

• 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

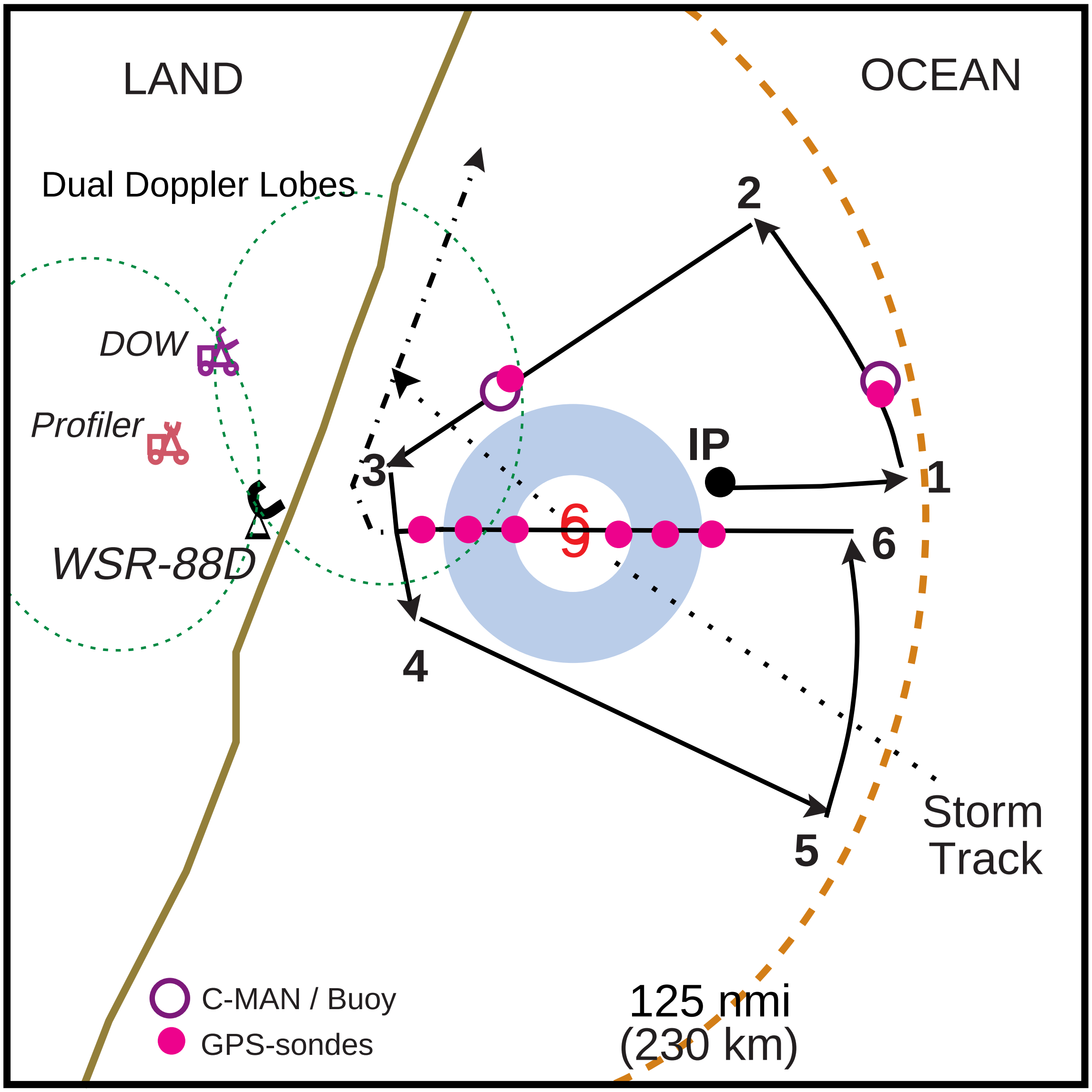


Fig. 19. Flight track for the dual-Doppler option that covers the inner core and surrounding rainbands.

• 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

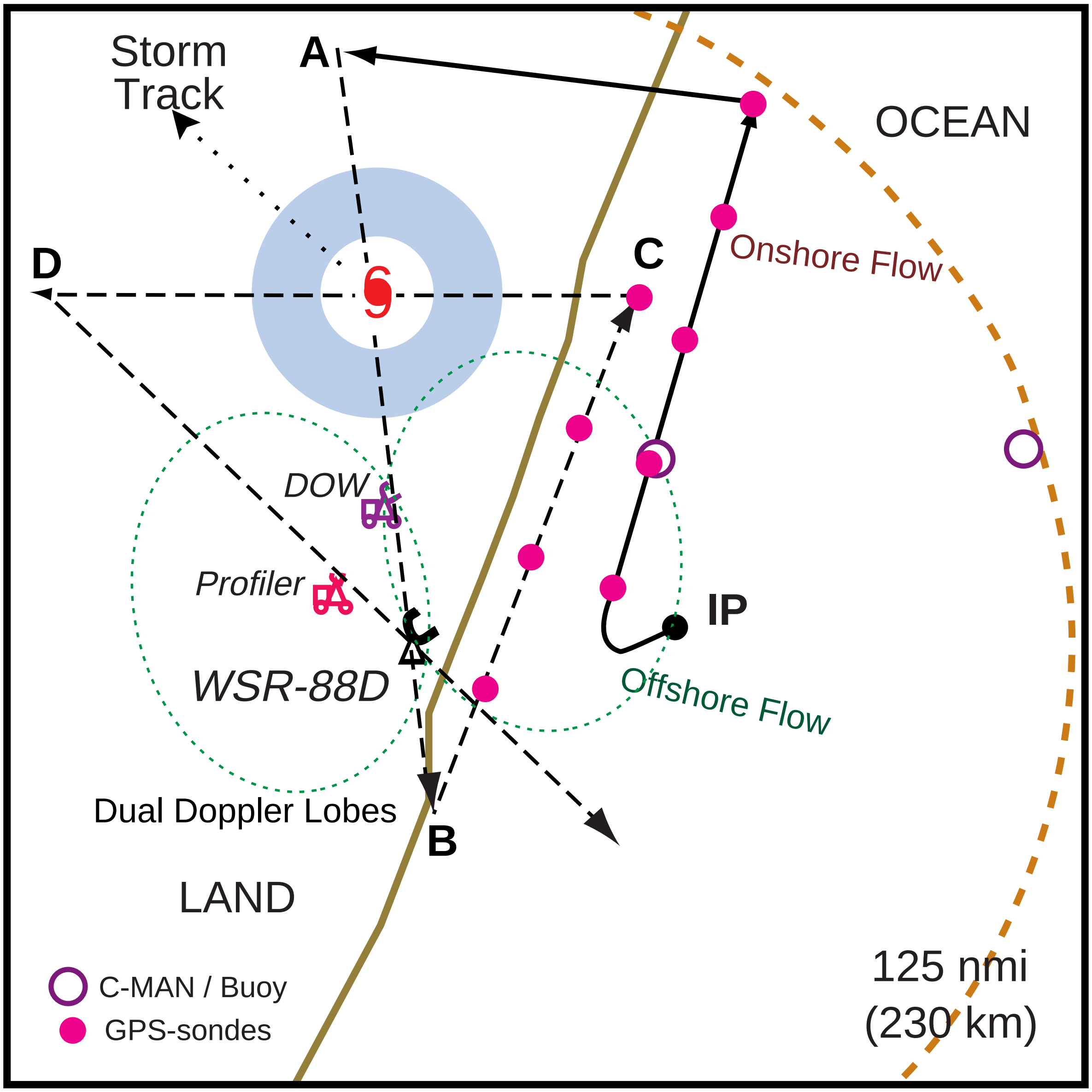


Fig. 20. Flight track for the real-time module with over flights of moored buoys and GPS-sonde drops for a storm after landfall.

• 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.

TROPICAL CYCLONE WINDFIELDS NEAR LANDFALL EXPERIMENT

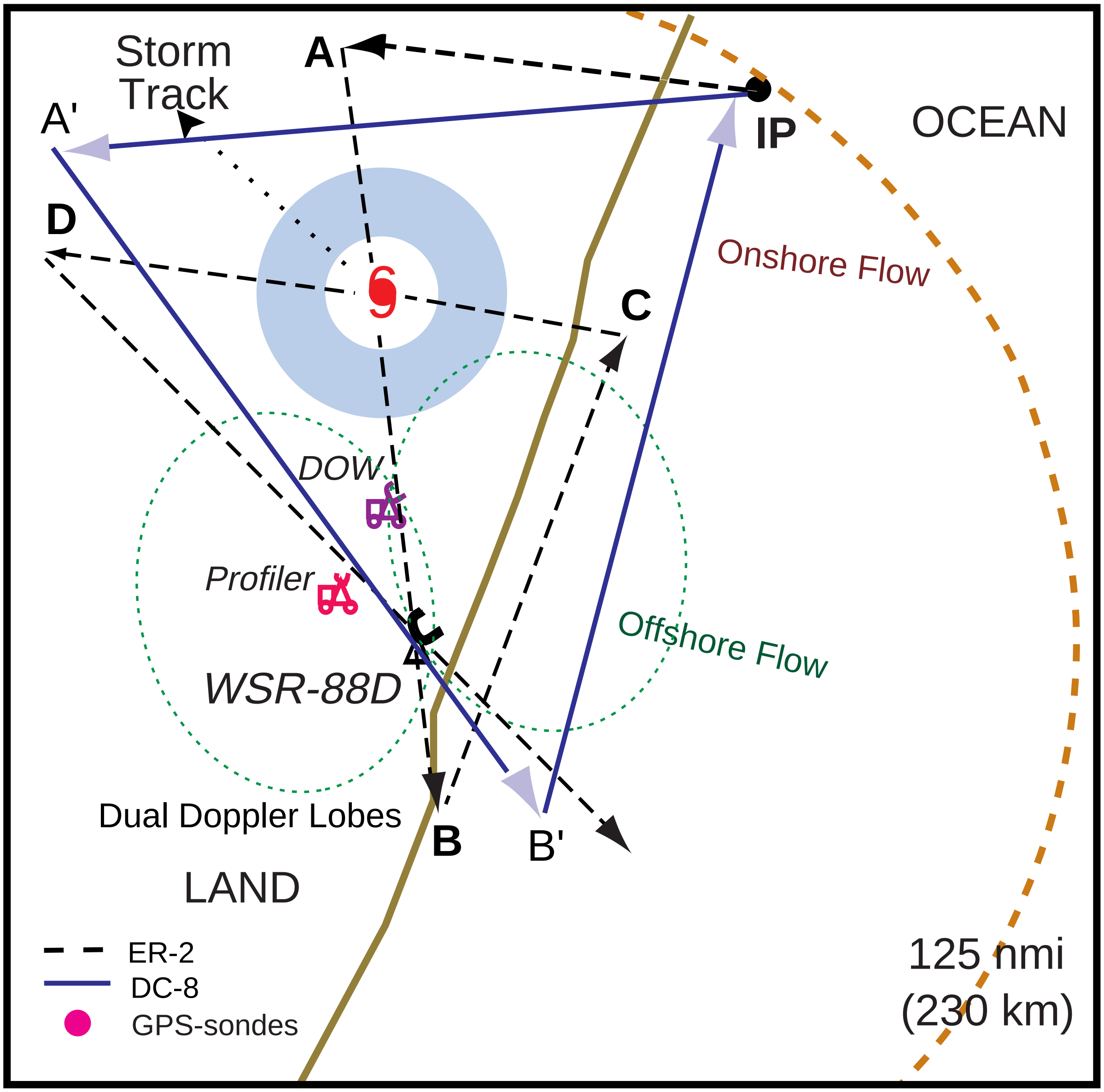


Fig. 21. Flight track for the DC-8 and ER-2 module for a storm after landfall.

• Note 1.	Begin pattern after execution of the coastal survey option. Execute figure-4 (ER-2)or triangle (DC-8) pattern on circulation center with >60 nmi (110 km) legs at 37,000 ft (DC-8) (solid line).and 67,000 (ER-2) altitude (dashed line).
• Note 2.	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.

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 problems associated with these storms. Forecasters from the three American TC forecast centers, NHC, the Central Pacific Hurricane Center (CPHC) and the Joint Typhoon Warning Center (JTWC), have recommended that their highest priority in TC research is the improvement in hurricane wind field and intensity forecasting. The Hurricanes at Landfall (HaL) program was 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, including surface wave run-up, 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 or 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**: *(48-72 h before landfall; one aircraft)*
During the Pre-landfall portion of this experiment one WP-3D aircraft with AXBT/AXCP/AXCTD 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. 22a and 22b (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:** *(12-36 h before landfall; two aircraft, two flights)*
During the near-landfall phase two WP-3D aircraft with AXBT/AXCP/AXCTD launch capabilities is required. The flight plan ,outlined in Fig. 23, commences as the TC begins to interact with either the symmetric or asymmetric ocean feature. 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/AXCTD 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. 22a and 22b, *except* **no** 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.

A major CAMEX-3 objective is to obtain wind and precipitation measurements in the inner core of the storm using the remote sensors on the DC-8 and ER-2 (Appendix B). These types of observations can greatly enhance the TC Air Sea Interaction Near-landfall Experiment and can provide ground truth for the remote sensing instruments. The DC-8 aircraft and the ER-2 will take off 1/2 to 1- h after the WP-3D aircraft in order to coordinate the in-storm pattern (Fig. 5). Subject to safety and operational constraints, the DC-8 will climb to the 250-mb level (about FL 370) and the ER-2 climbs to 65,000 ft. Both aircraft fly over the ground test facility on Andros Island on their way to the storm. The WP-3D lead scientist will pass storm position, storm motion, and a recommended IP to the DC-8 lead scientist. Both aircraft will fly a pattern similar to Fig. 5a. The inner core pattern (Fig. 5b), designed to provide detailed observations of the eye and eyewall structure, can be executed at the discretion of the DC-8 lead scientist in coordination with the WP-3D lead scientist.

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/AXCTD instrumentation, Surface Contour Radar (SCR), 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, AXCTDs 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. The SCR measures directional wave spectra and mean surface elevation for input to flux parameterizations and storm surge models.

TROPICAL CYCLONE AIR-SEA INTERACTION EXPERIMENT

Pre-Landfall Symmetric Ocean Feature Module

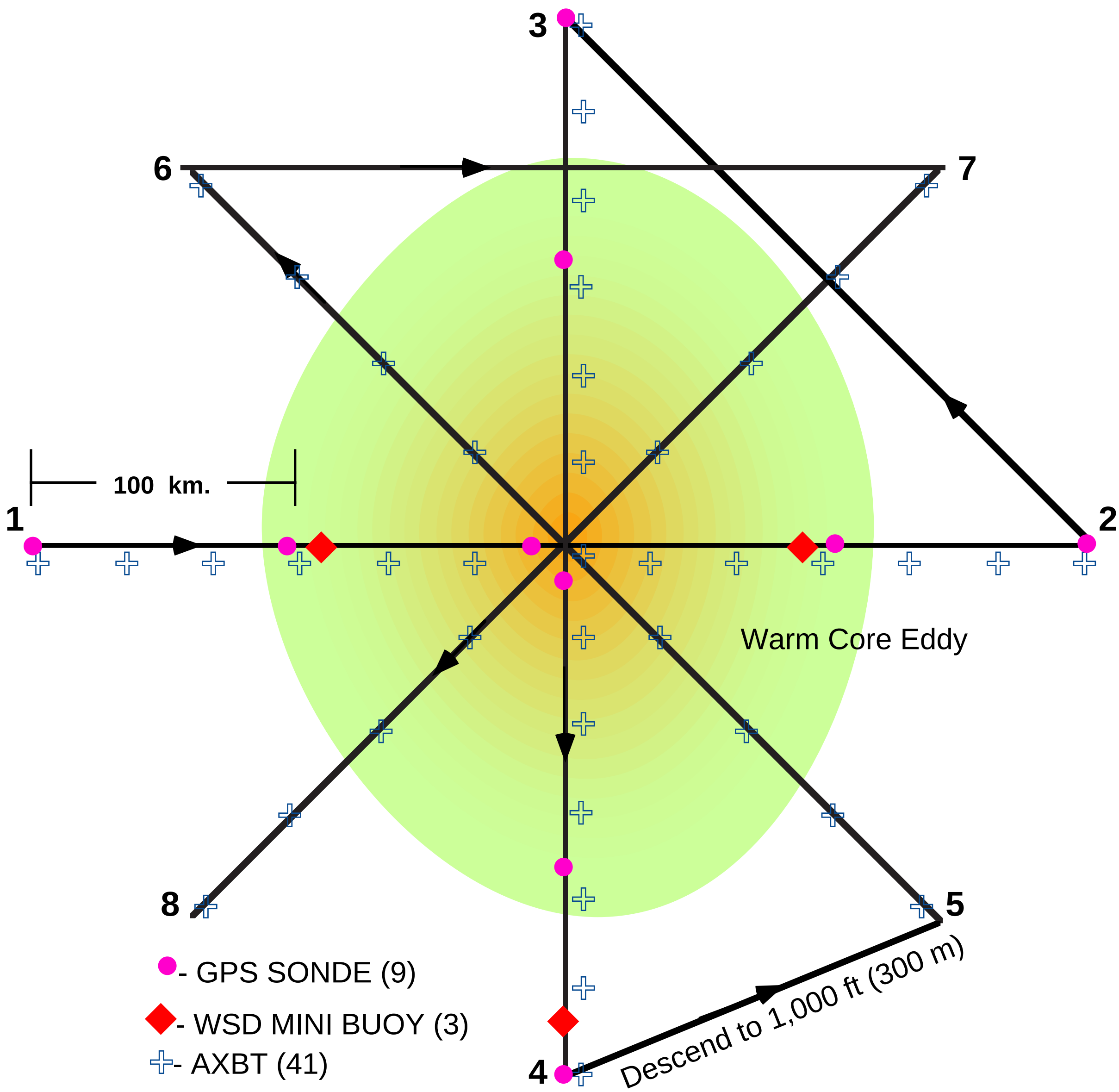


Fig. 22. **(a) Pre-landfall symmetric ocean feature survey pattern**

• 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

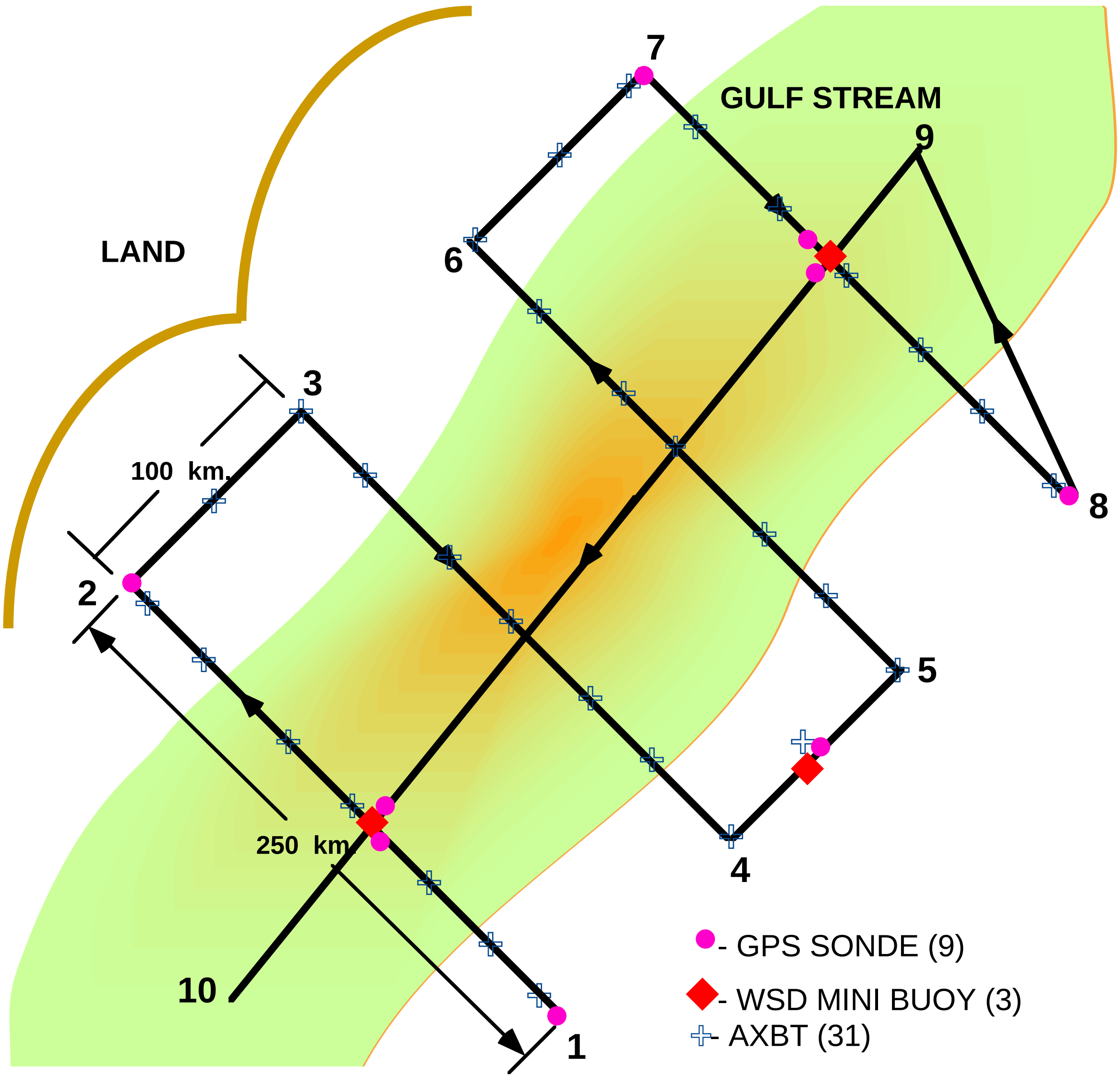


Fig. 22. **(b) Pre-storm asymmetric ocean feature survey pattern**

• 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

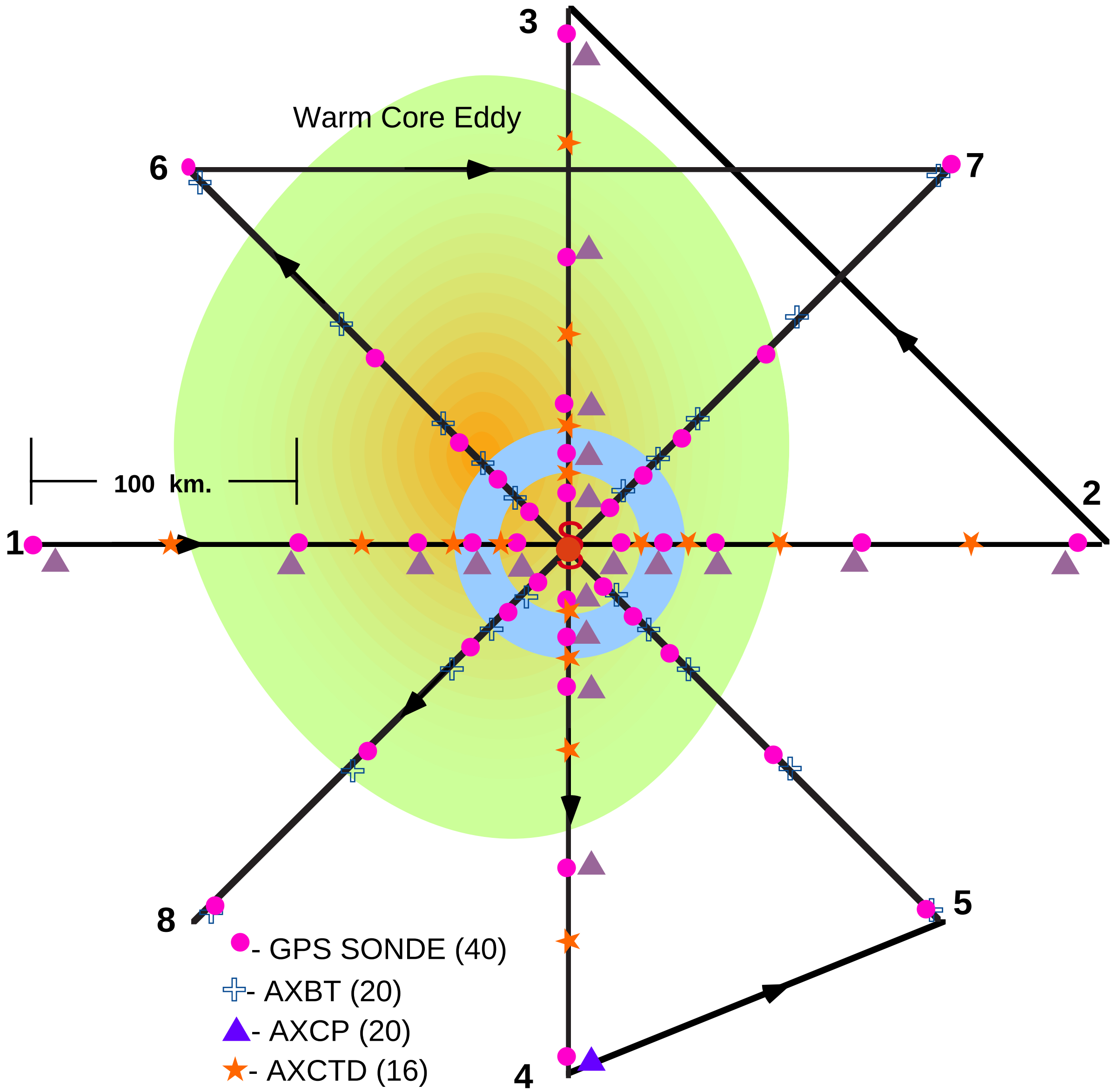


Fig. 23. **Near-landfall survey pattern**

• 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.

How do changes in the energy content of the low-level inflow to the eyewall affect tropical cyclone intensity ? Can we develop techniques that use the new GPS-sondes that will allow one to monitor the changes in the inflow and eventually make forecasts of intensity? Empirical and theoretical studies have developed a relationship ($\delta P = -3\ \delta\theta_e$) that highlights how the increase of the mean equivalent potential temperature ($\delta\theta_e$) of the eyewall updraft column affects the lowering of minimum sea level pressure below a threshold of approximately 1000 mb (δP). If the mean θ_e of the inflow increases 20 K the MSLP of the hurricane deepens by about 60 mb, all other factors being held constant. Measurement of the evolving energy content will allow estimates of the fluxes at the top and bottom of the inflow layer and provide a clearer view of the air-sea interaction processes that affect tropical cyclone intensity.

The problem is that the processes that control $\delta\theta_e$ in the inflow have been difficult to quantify. The high sea state and copious amounts of spray push the use of the bulk aerodynamic equations into a realm for which there are no supporting data. Our understanding of the fluxes at the top of either the mixed layer or the thicker inflow layer is not well known. There are no reliable measurements of the flux at the top of the inflow layer, nor are there reliable estimates of the depth of the inflow. This is despite the conclusions from budget studies and simple numerical models that identify the mixing at the top of these layers as vital part of the hurricane circulation.

Recently analyses for an intense rainband in Hurricane Gilbert (1988) support the conjecture that the fluxes at the top of the inflow layer are large and downward into the inflow layer. This is counter to the typical situation where the flux of energy is out of the layer and into the middle troposphere. These fluxes can rival the fluxes at the air-sea interface. There appeared to be regions in Gilbert where the inflow layer rapidly increased in θ_e, and other regions where the flux divergence of θ_e resulted in very slowly changing conditions. Rainband circulations have been implicated in this highly asymmetric input of energy into the inflow. Strong rainbands like the one sampled in Gilbert are similar in circulation to an eyewall. We hypothesize that the eyewall circulation itself will have a profound affect on its own inflow, and may lead to a recycling of high θ_e into the top of the inflow layer.

Currently we have little information on the characteristics of the inflow within 45 nmi (75 km) of the eyewall. The new GPS-sondes provide us with an opportunity to sample this region safely and efficiently. This experiment ma, conducted as a piggy-back experiment and would work especially well with reconnaissance missions when a hurricane is threatening landfall. Eventually we would like to develop the most efficient strategy to deploy the GPS-sondes so we can predict changes in the intensity of the tropical cyclone. After a few experiments focused on the GPS-sondes are analyzed the experiment can be lengthened to include a more complete sampling of the inflow through the use of in situ turbulent measurements conducted with the WP-3Ds.

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.
- Estimate the sensible and latent heat flux divergence for the inflow layer.
- Determine how different inflow trajectories that may pass over land, and warmer or cooler waters alter the energy content of the inflow.
- Determine how the vertical exchange in and near the eyewall affects the energy content of the inflow.
- Develop efficient schemes to monitor energy content of the inflow using the GPS sondes.
- Assess how changes in the energy content of the inflow affect hurricane intensity.
- Document changes in microphysics and rainfall characteristics in the storm.
- Obtain a remote sensing data base suitable for evaluation and improvement of satellite and ground validation rainfall estimation algorithms for TCs.

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. 24). AC2 will fly ~80 nmi (150 km) legs at ~14,000 ft (4 km) and rendezvous near AC1 at **4** (Fig. 24). 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. 25). 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. 25 until the inner aircraft nears the eyewall.

At **7** in Fig. 25, 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. 26). 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. 26). 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 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. 24-26 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. 27 (**4-5-6-7**). GPS-sondes would be dropped as seen in Figs. 24-26.

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 STRUCTURE EXPERIMENT

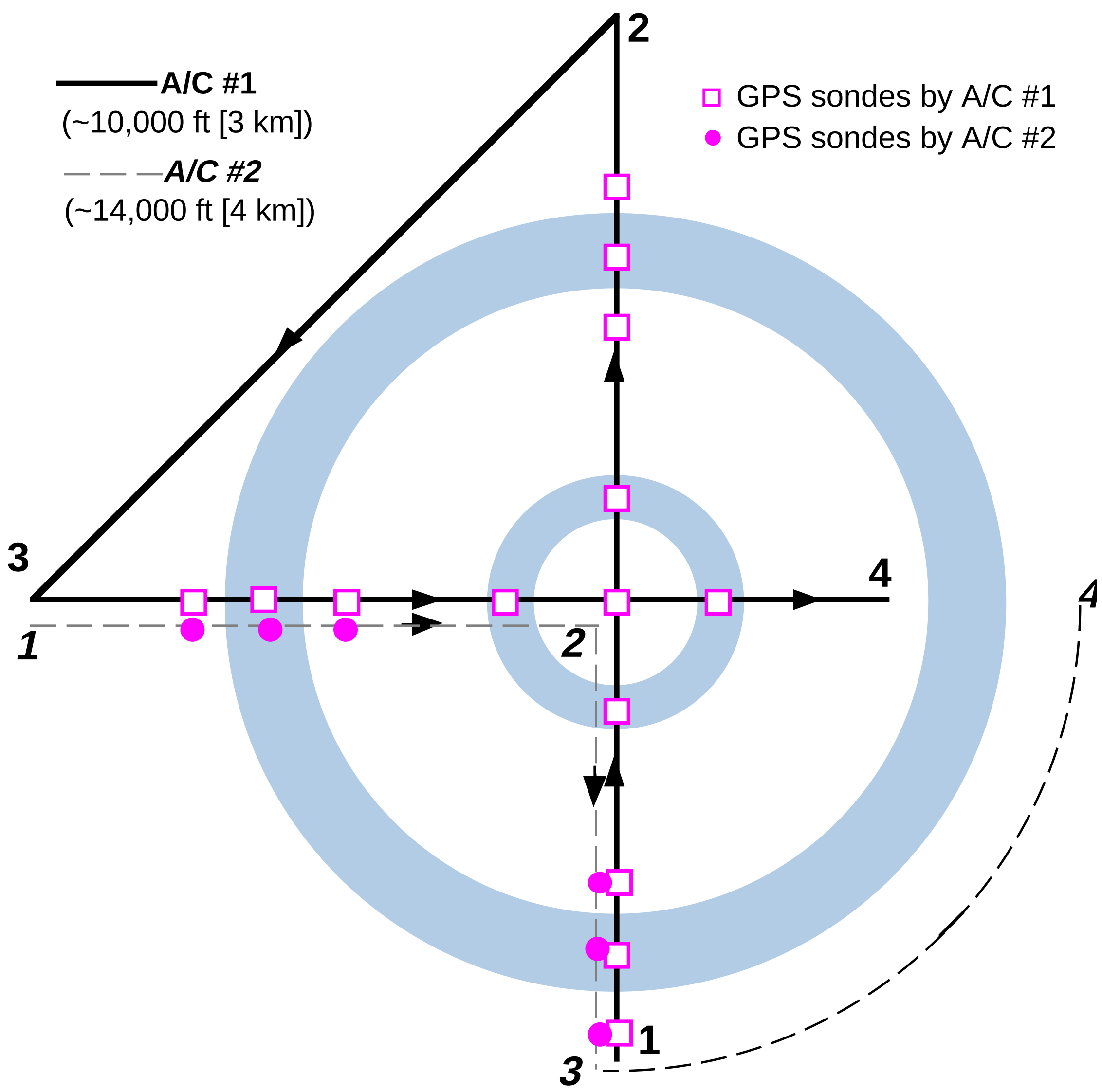


Fig. 24. Beginning Survey Pattern.

• 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

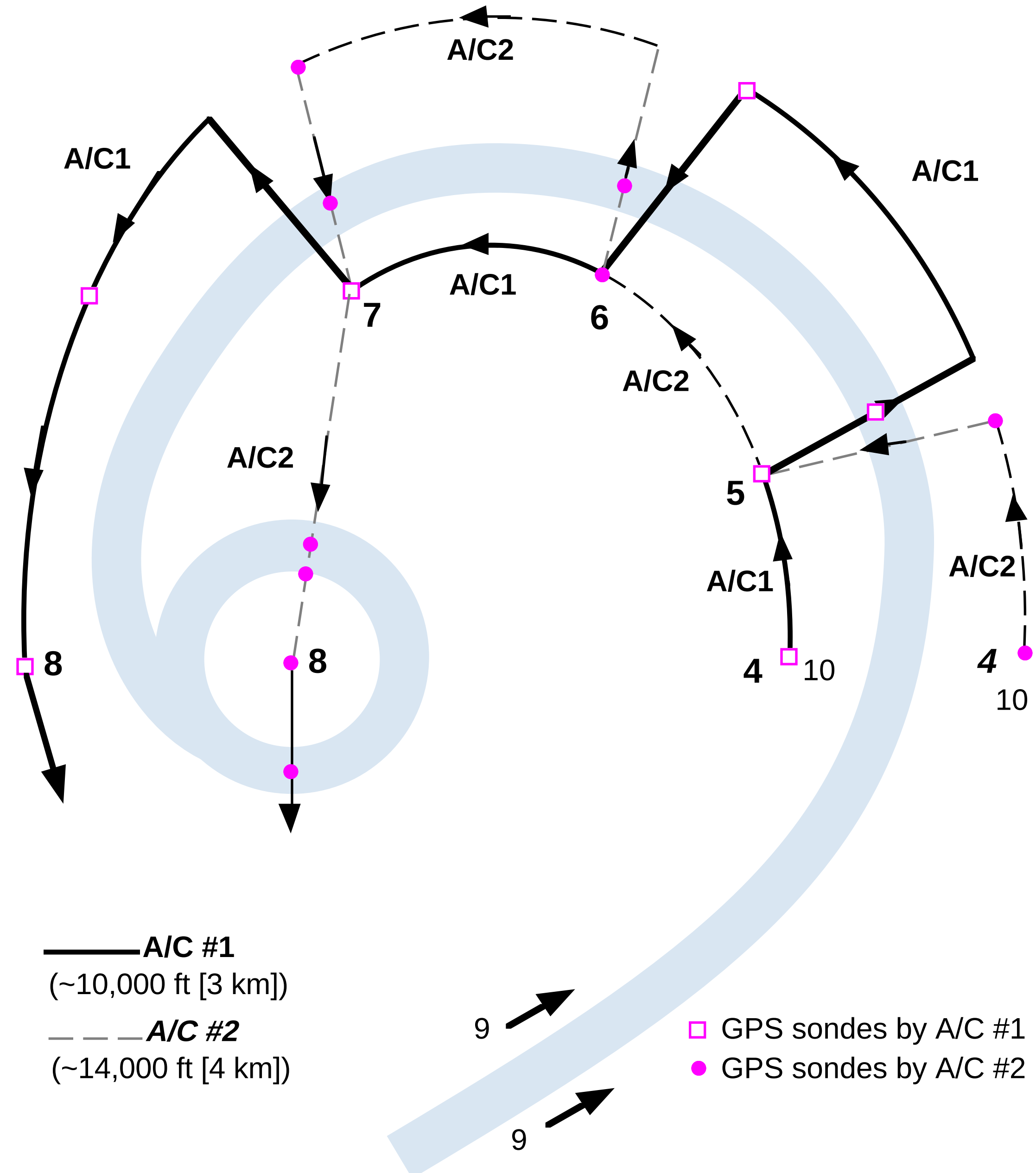


Fig. 25. Principal Band /Concentric Eyewall Option.

• 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

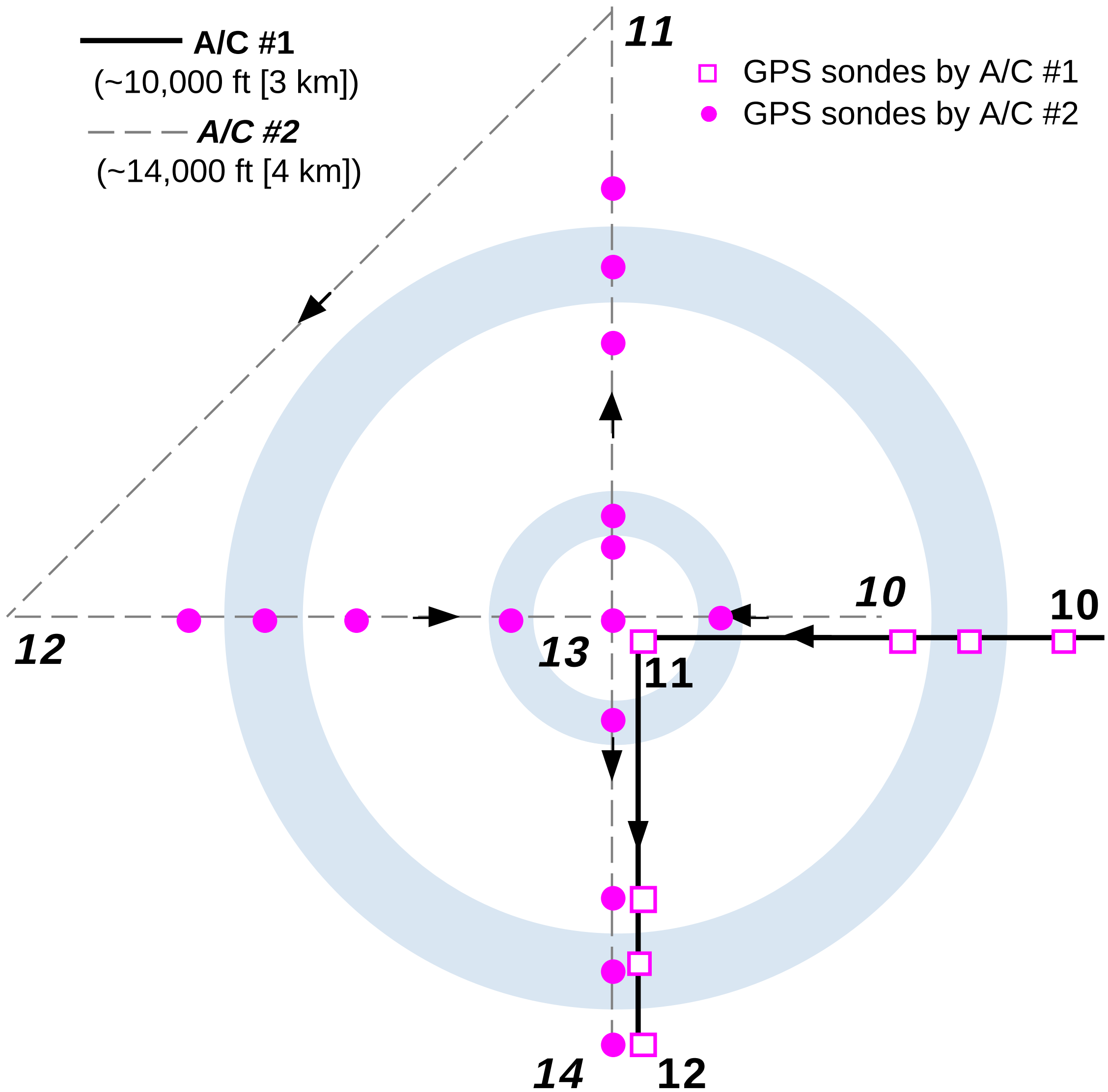


Fig. 26. Final Survey.

• 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.

A major CAMEX-3 objective is to obtain wind and precipitation measurements in the inner core of the storm using the remote sensors on the DC-8 and ER-2 (Appendix B). These types of observations can greatly enhance the Rainband Structure Experiment and can provide ground truth for the remote sensing instruments. The DC-8 aircraft and the ER-2 will take off 1/2 to 1- h after the WP-3D aircraft in order to coordinate the in-storm pattern (Fig. 5). Subject to safety and operational constraints, the DC-8 will climb to the 250-mb level (about FL 370) and the ER-2 climbs to 65,000 ft. Both aircraft fly over the ground test facility on Andros Island on their way to the storm. The WP-3D lead scientist will pass storm position, storm motion, and a recommended IP to the DC-8 lead scientist. Both aircraft will fly a pattern similar to Fig. 5a. The inner core pattern (Fig. 5b), designed to provide detailed observations of the eye and eyewall structure, can be executed at the discretion of the DC-8 lead scientist in coordination with the WP-3D lead scientist.

- **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. 27). 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 Thermodynamic Structure Module**: This module requires one WP-3D flying above the inflow layer (8,000 to 10,000 ft). The WP-3D deploys 6-8 GPS-sondes and an occasional AXBT along a curved track approximately 60 nmi (100 km) long that roughly mimics the inflow trajectory for air in the subcloud and lower cloud layers. Deployment of the GPS-sondes occurs between the eyewall outer edge and the inner edge of any convective rainband found at greater radial distance. If there are no rainbands then sonde deployment may cease at approximately 60 nmi (100 km) radial distance from the circulation center. Fig. 28a is a plan view of the experiment, Fig. 28b is a radius-height cross-section of the scheme. Note that shorter times between each GPS launch are preferred when the aircraft is near the eyewall. A sonde should also be deployed in the eye. The mission easily can be accomplished when the aircraft is conducting a reconnaissance mission for NHC. Instead of cardinal headings to and from the eye the aircraft follows a spiral path in and out of the circulation center. A typical spiral path should be 20-40° from a tangent to a given radius. Flight time for 60 nmi (100 km) is about 15-20 min.

GPS-sondes are deployed every 6-9 nmi (10-15 km) starting from about 6 nmi (10 km) from the outer edge of the eyewall to insure that the sonde falls outside of the main updraft and rain. After four sondes are in the air and the first sonde splashes down a new one may be deployed. The design assumes that 4 sondes may be in the air simultaneously and that the sonde descends at about 10 m s^{-1}.

A single spiral in or out will provide a view of how energy content changes along a trajectory for one portion of the storm. If several trajectories are sampled then energy content and cyclone intensity can be studied. Judicious choice of the inflow trajectories to be flown is made by the airborne mission scientist and would likely include sampling inflow from the southeast and from the northwest as shown in Fig. 28a.

Turbulent flux option: If a WP-3D is equipped with the high frequency temperature and moisture sensors then a series of legs may be flown in the region where sondes were previously dropped between the eyewall and a convective rainband. These legs are again approximately parallel to the low level inflow and are designed to allow one to estimate the sensible and latent heat flux divergence in the inflow layer. The levels chosen are a function of the structure revealed by one or more of the GPS-sondes. Legs should be 37-50 nmi (60-80 km) long. Typical altitudes would be 8,000, 6,500, 5,000, 3,000, 2,000, 1,000, and 500 ft; these levels may be adjusted depending on the altitude of the top of the inflow and mixed layers. It is desirable to have 2 legs above the inflow, the rest within the inflow. The lower levels are flown only if the turbulence and visibility are assessed as safe. At no time does the aircraft need to fly into rainbands, the eyewall, or any strong cells in between these two features. On the first, highest leg the aircraft should deploy sondes at every 12 nmi (20 km) to assess any evolution of the inflow from the prior GPS deployment stage. Fig. 28c shows the flight pattern. The total time for this option is about 2 h.

The turbulent flux option is recommended *only* if the flux instrumentation is operational and after a few experiments with the GPS alone have been accomplished.

RAINBAND STRUCTURE EXPERIMENT

Single Aircraft Option

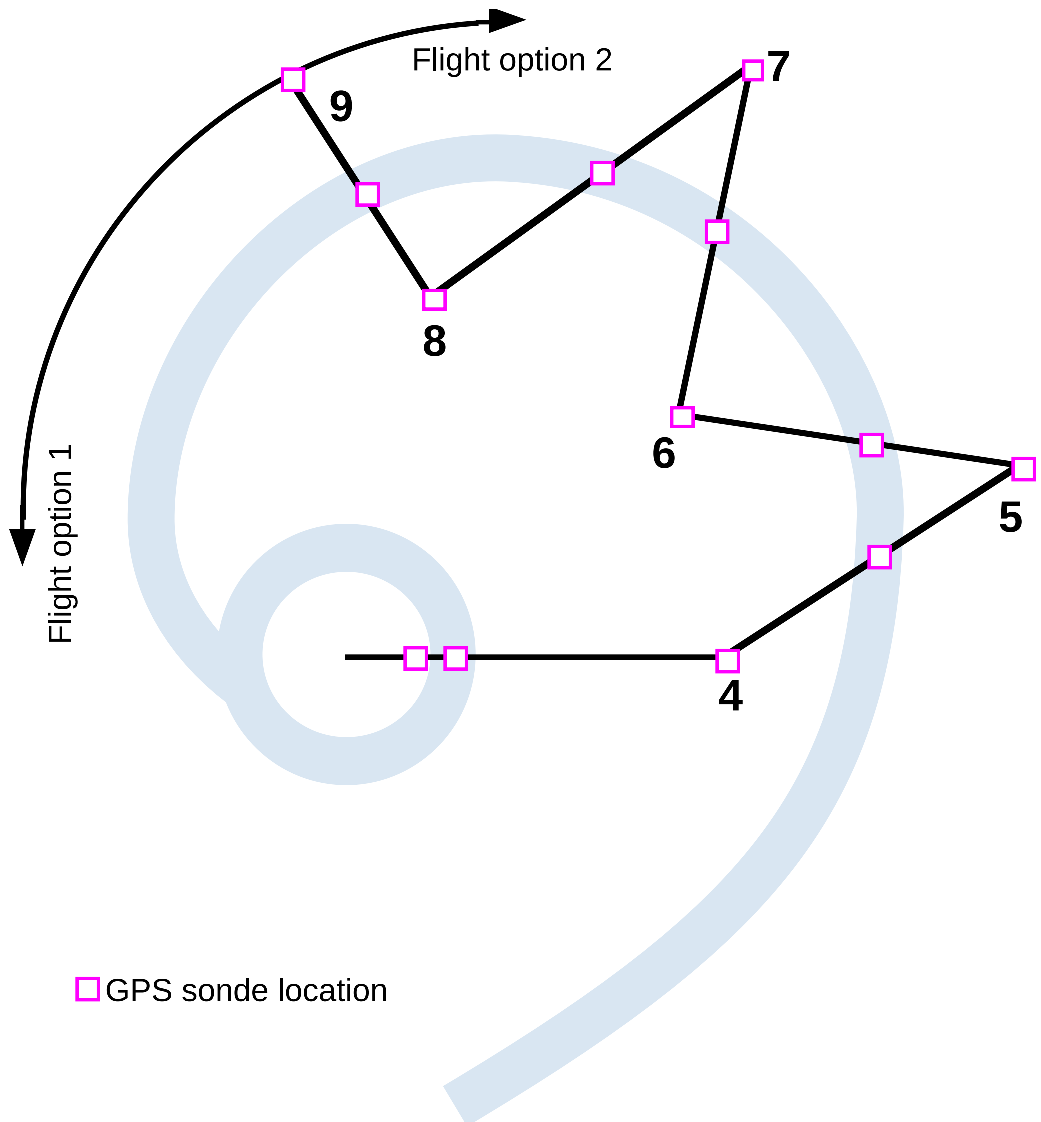


Fig. 27. Rainband Module—Single Aircraft Option.

• 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.

RAINBAND STRUCTURE EXPERIMENT

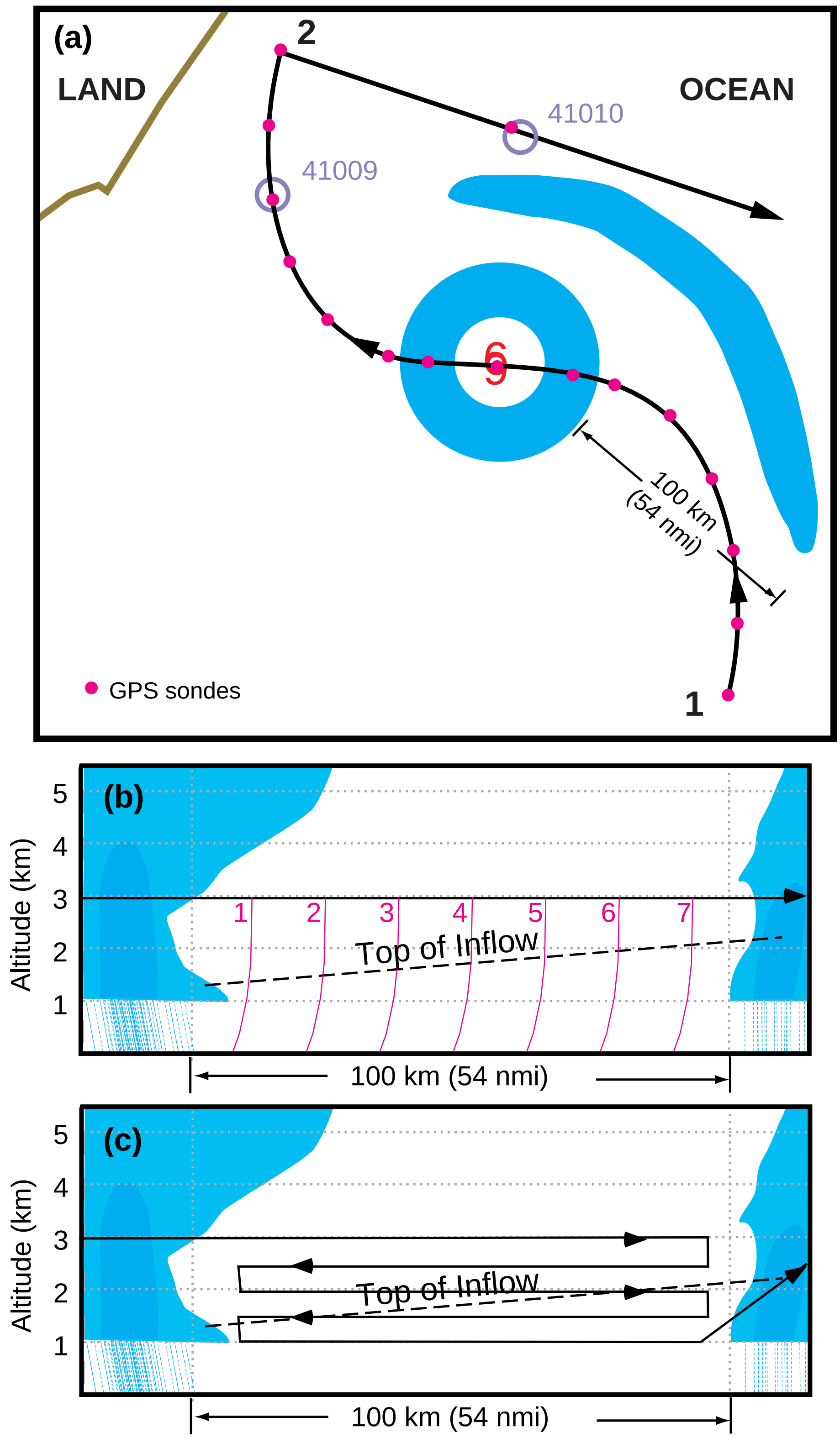


Fig. 28. Rainband Thermodynamic Structure Module (a) Plan view; and Aircraft track-height depiction of (b) the GPS deployment experiment and (c) turbulent flux experiment.

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 data sets allow further investigation of the implications CG lightning has 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 the vector electric field and an induction ring that measures the charge on individual particles.

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.
- Document changes in microphysics and rainfall characteristics in the storm.
- Obtain a remote sensing data base suitable for evaluation and improvement of satellite and ground validation rainfall estimation algorithms for TCs.

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. 29), and leg lengths shall be altered as necessary to achieve this. This out and back pattern (**1-2-1** in Fig. 29) 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. 29) 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. 30) through the middle of the band the feature. Each downwind pass (Fig. 30, **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. 30, **3-4**) upwind to the start of the band. The 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

ELECTRIFICATION OF TROPICAL CYCLONE CONVECTION EXPERIMENT

Eyewall Module

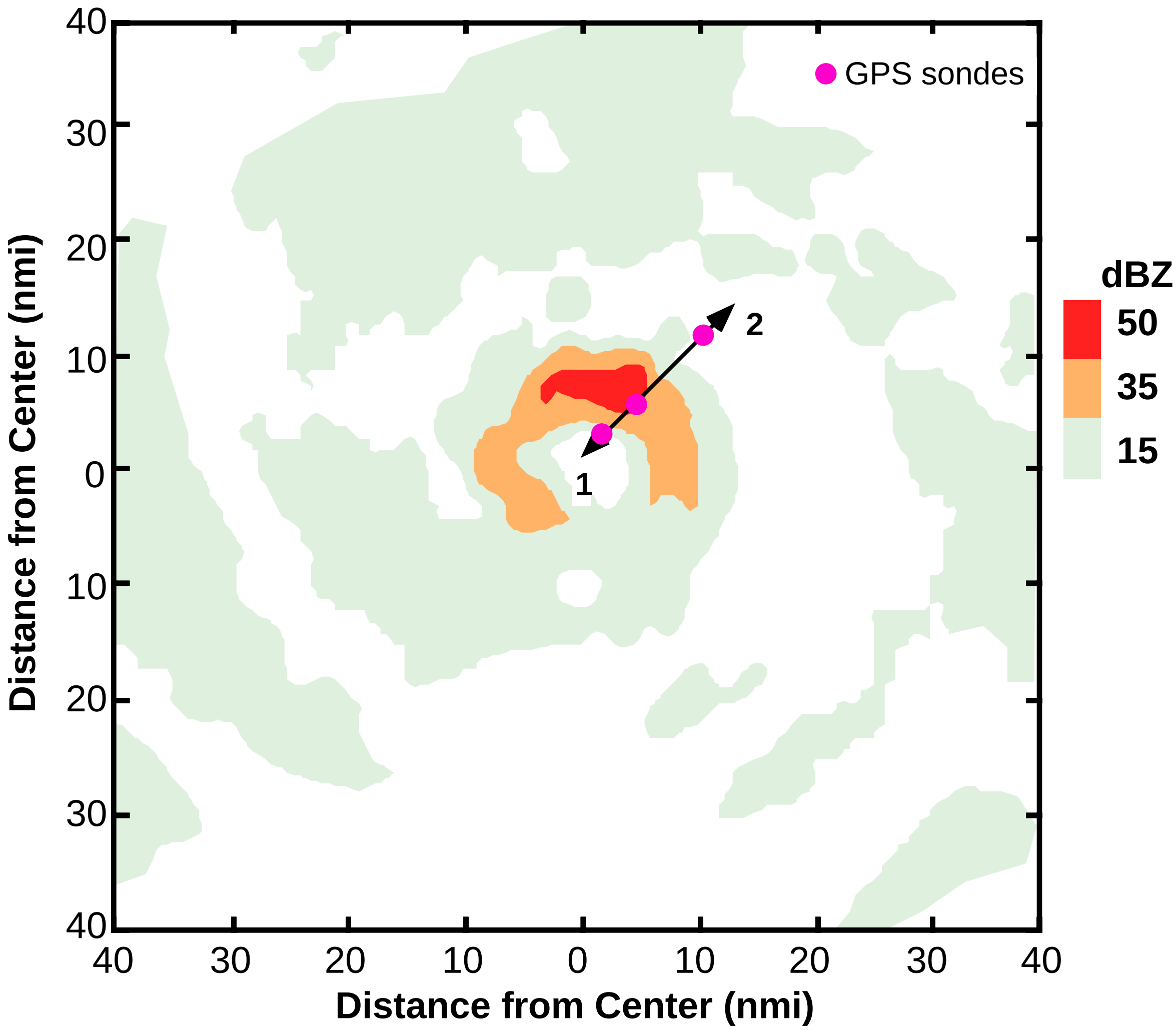


Fig. 29. Convection/Eyewall module flight pattern.

• 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

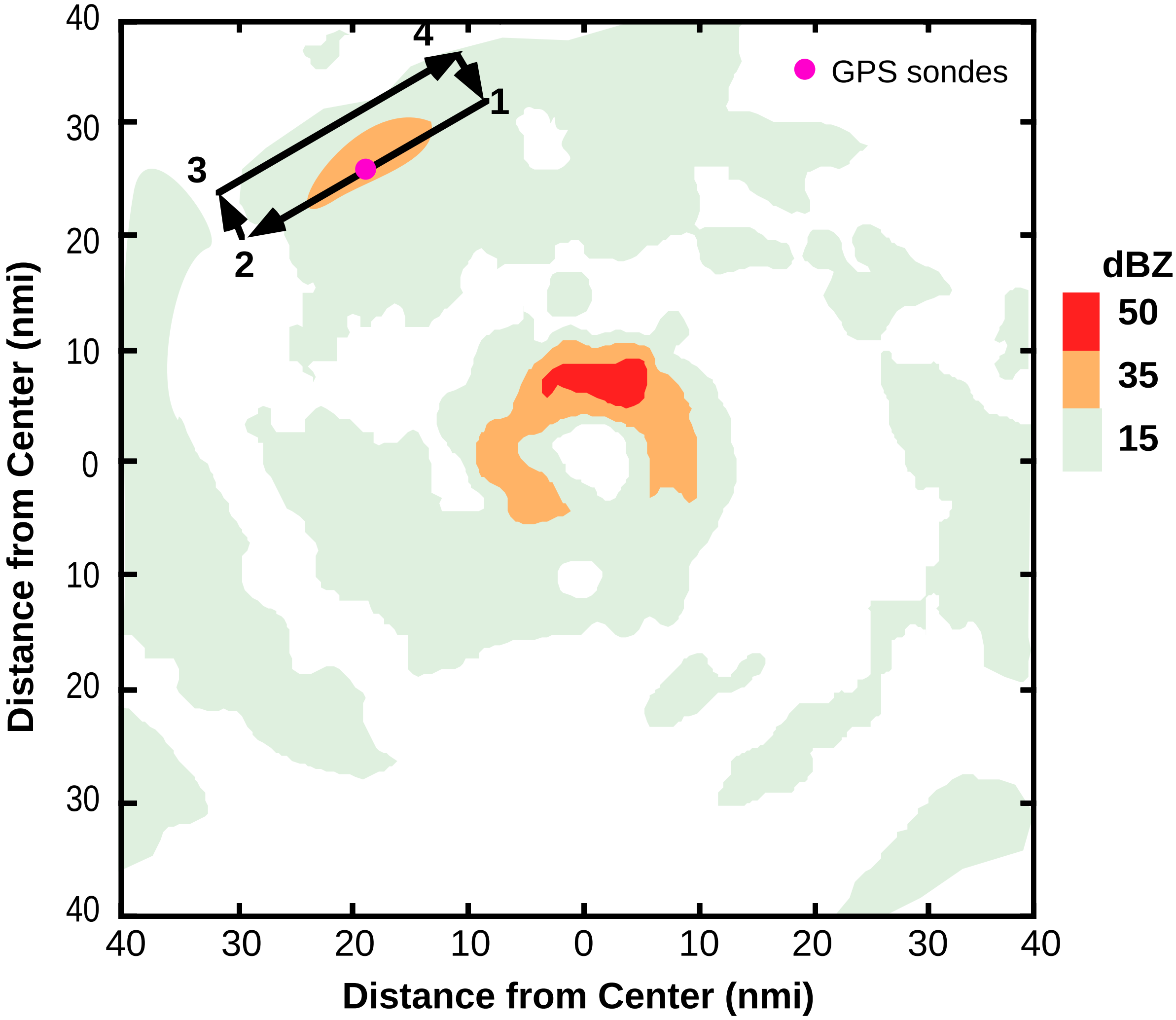


Fig. 30. Convection/Rainband module flight pattern.

• 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.

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. 31). 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 32a) 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. 32b) 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. 30, 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.

A major CAMEX-3 objective is to obtain wind, precipitation, and electric field measurements in the inner core of the storm using in situ and remote sensors on the DC-8 and ER-2 (Appendix B). These types of observations can greatly enhance the Electrification of TC Convection Experiment and can provide ground truth for the remote sensing instruments. The DC-8 aircraft and the ER-2 will take off 1/2 to 1- h after the WP-3D aircraft in order to coordinate the in-storm pattern (Fig. 5). Subject to safety and operational constraints, the DC-8 will climb to the 250-mb level (about FL 370) and the ER-2 climbs to 65,000 ft. Both aircraft fly over the ground test facility on Andros Island on their way to the storm. The WP-3D lead scientist will pass storm position, storm motion, and a recommended IP to the DC-8 lead scientist. Both aircraft will fly a pattern similar to Fig. 5a. The inner core pattern (Fig. 5b), designed to provide detailed observations of the eye and eyewall structure, can be executed at the discretion of the DC-8 lead scientist in coordination with the WP-3D lead scientist.

ELECTRIFICATION OF TROPICAL CYCLONE CONVECTION EXPERIMENT

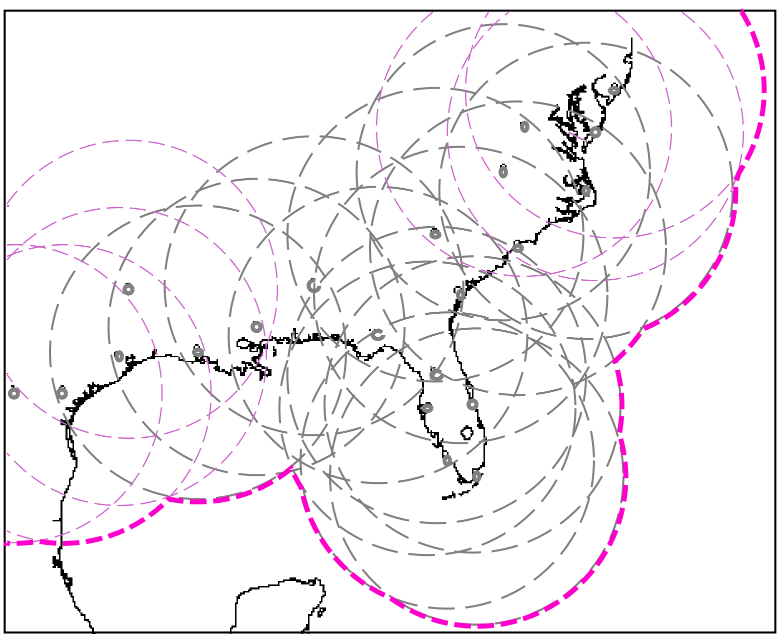


Fig. 31. Lightning direction finders (DFs) of the NLDN. Rings are at 325 nmi (600 km) radius from each site. The o denotes DF location.

ELECTRIFICATION OF TROPICAL CYCLONE CONVECTION EXPERIMENT

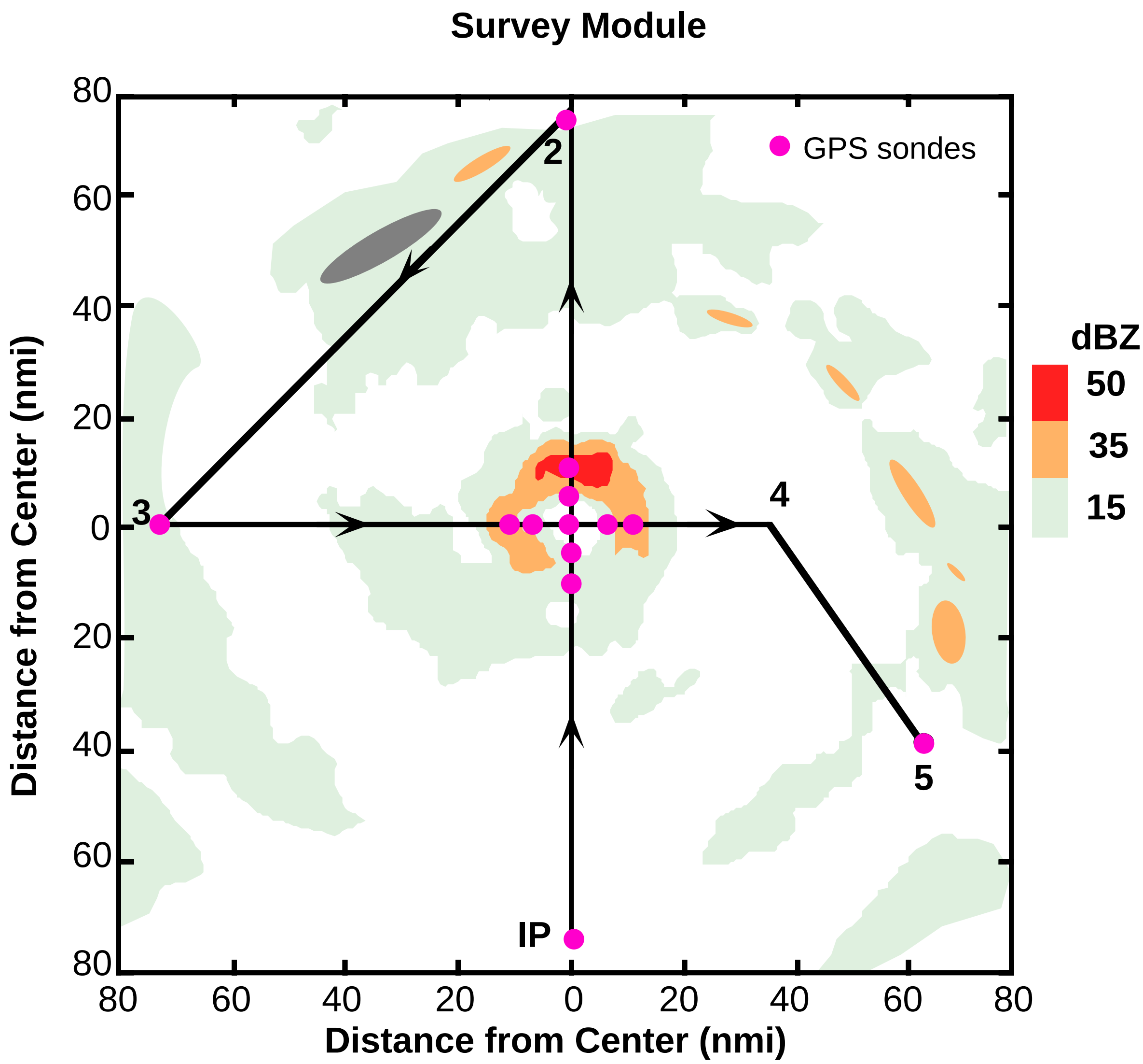


Fig. 32. (a) Convection/Survey module flight pattern.

• 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

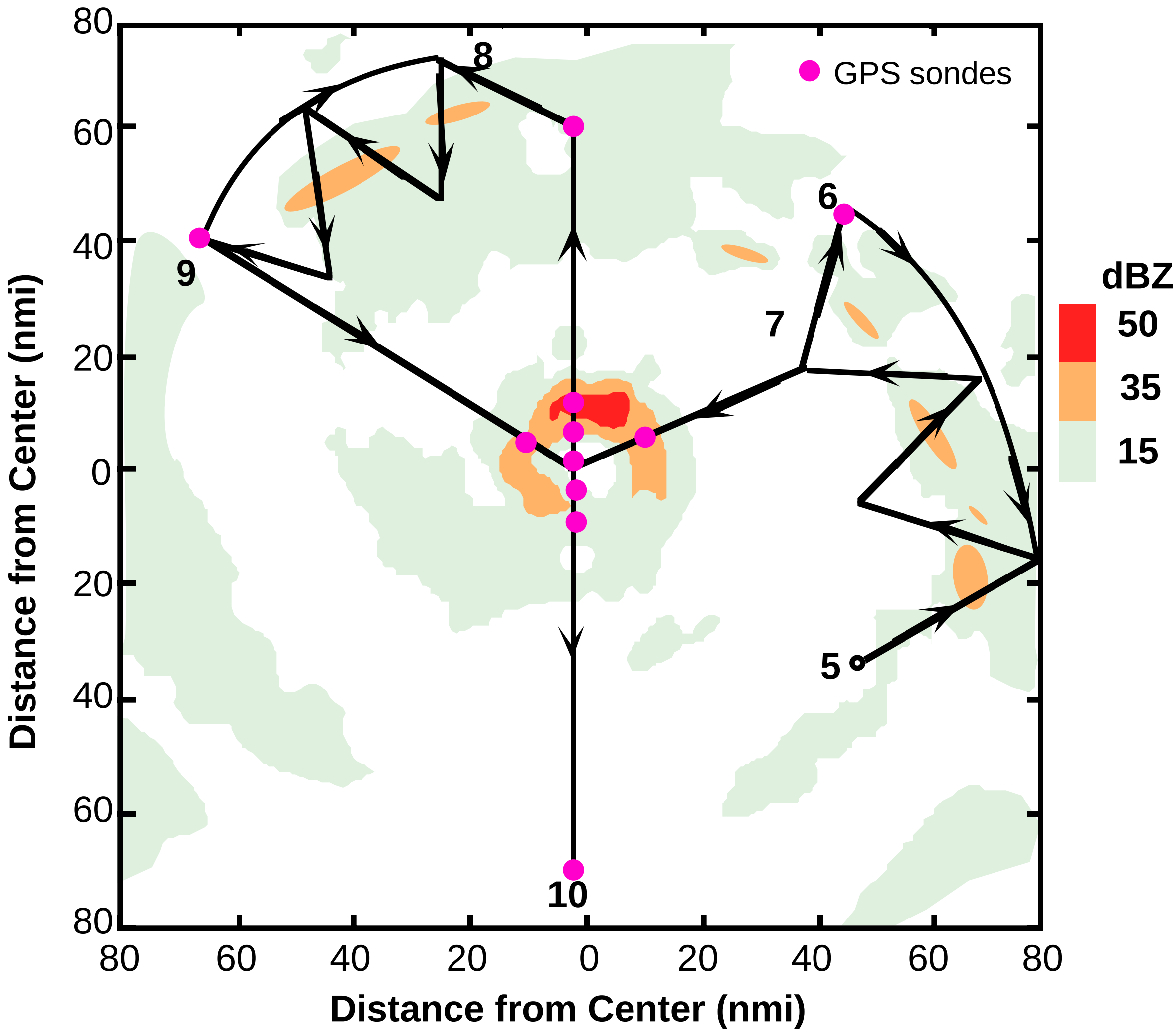


Fig. 32. (b) Convection/Survey rainband module flight pattern.

• 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.

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.
- Document changes in microphysics and rainfall characteristics in the storm.
- Obtain a remote sensing data base suitable for evaluation and improvement of satellite and ground validation rainfall estimation algorithms for TCs.

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. 33a) 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. 33b). 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. 33a) 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.

A major CAMEX-3 objective is to obtain wind and precipitation measurements in the inner core of the storm using the remote sensors on the DC-8 and ER-2 (Appendix B). These types of observations can greatly enhance the Eyewall Vertical Motion Experiment and can provide ground truth for the remote sensing instruments. The DC-8 aircraft and the ER-2 will take off 1/2 to 1- h after the WP-3D aircraft in order to coordinate the in-storm pattern (Fig. 5). Subject to safety and operational constraints, the DC-8 will climb to the 250-mb level (about FL 370) and the ER-2 climbs to 65,000 ft. Both aircraft fly over the ground test facility on Andros Island on their way to the storm. The WP-3D lead scientist will pass storm position, storm motion, and a recommended IP to the DC-8 lead scientist. Both aircraft will fly a pattern similar to Fig. 5a. The inner core pattern (Fig. 5b), designed to provide detailed observations of the eye and eyewall structure, can be executed at the discretion of the DC-8 lead scientist in coordination with the WP-3D lead scientist.

EYEWALL VERTICAL MOTION STRUCTURE EXPERIMENT

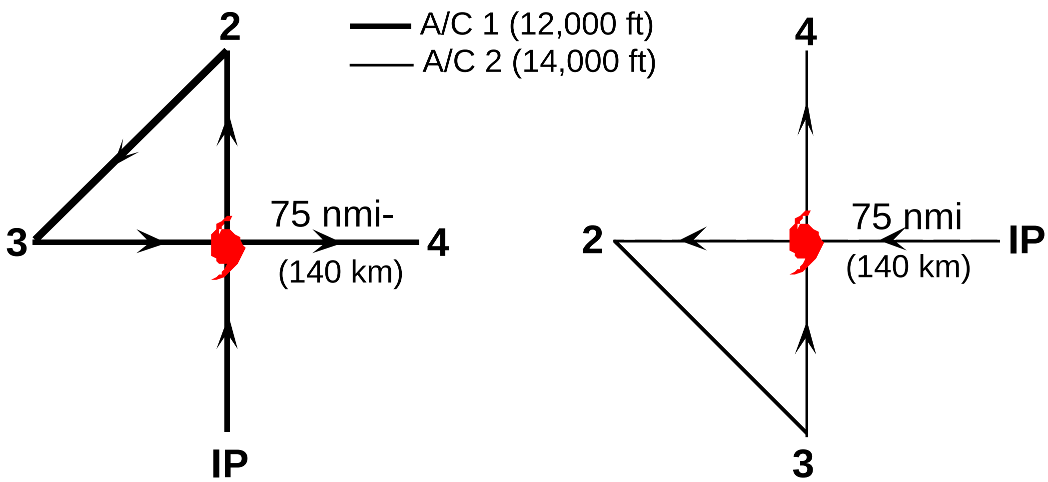


Fig. 33. (a) Coordinated dual-Doppler pattern

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

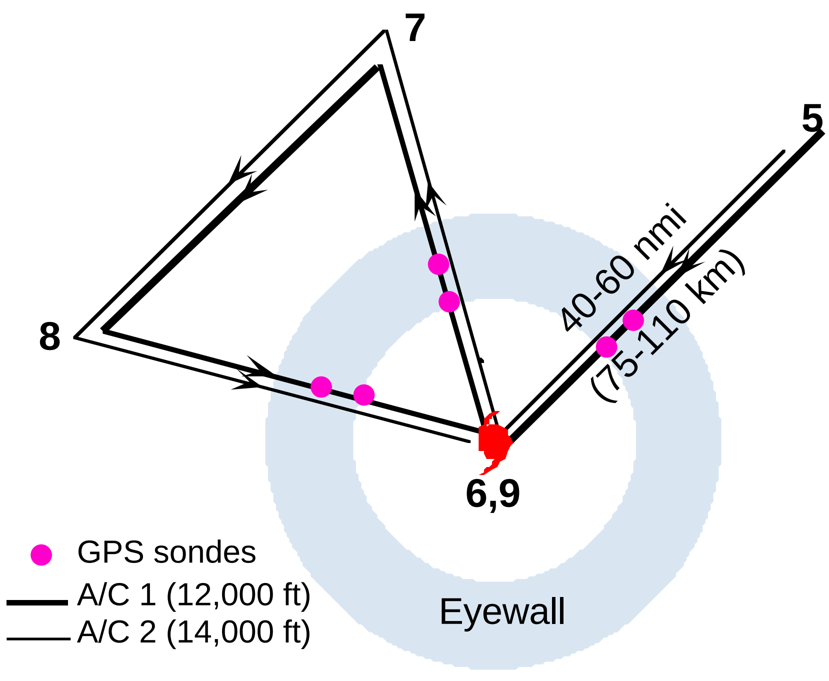


Fig. 33. (b) Eyewall dual-vertical incidence module

• 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. In particular this year the experiment will be coordinated with other TRMM validation experiments under the auspices of CAMEX-3 and the Texas-Florida Underflight (TEFLUN) Experiment which have assembled groundbased radars, profilers, and rain gages in central Florida near the Kennedy Space Center. 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.
- Perform underflights of the TRMM satellite to obtain a data base suitable for evaluation and improvement of satellite and ground validation rainfall estimation algorithms.

- 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.

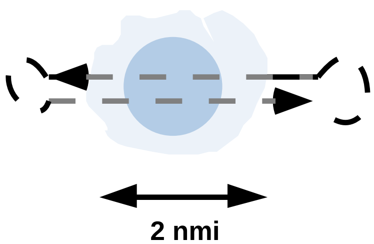
- Studying the relationship between initial and subsequent precipitation formation and the interaction between precipitation loading and the dynamics of the convective cell.

- 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. 34). 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. These missions can be conducted in conjunction with NASA DC-8 and ER-2 or the University of North Dakota Citation flights in support of TEFLUN or CAMEX-3.

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. 34, 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



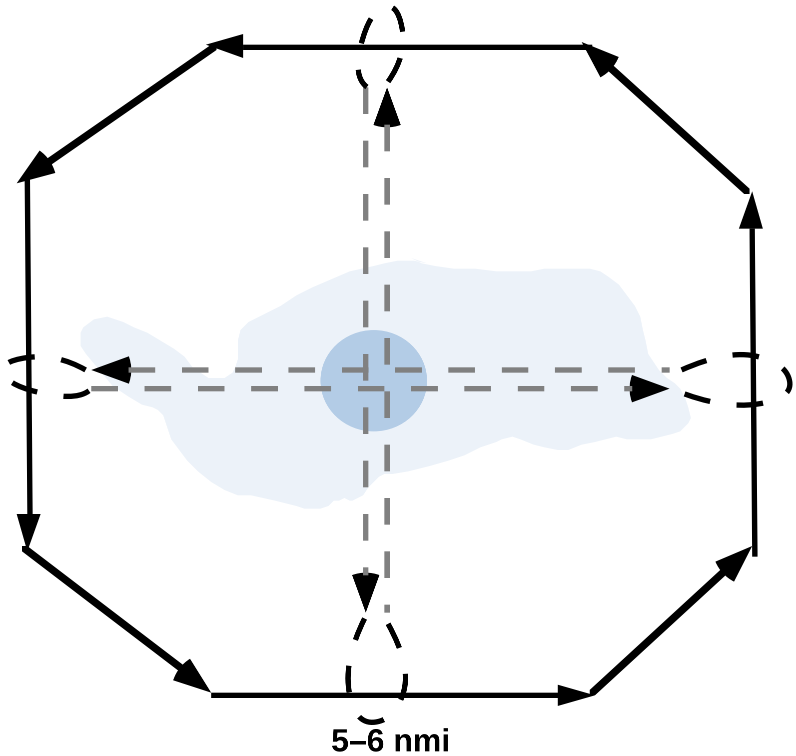


Fig. 34. (a) Initial Cloud Stage

Fig. 34. (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:

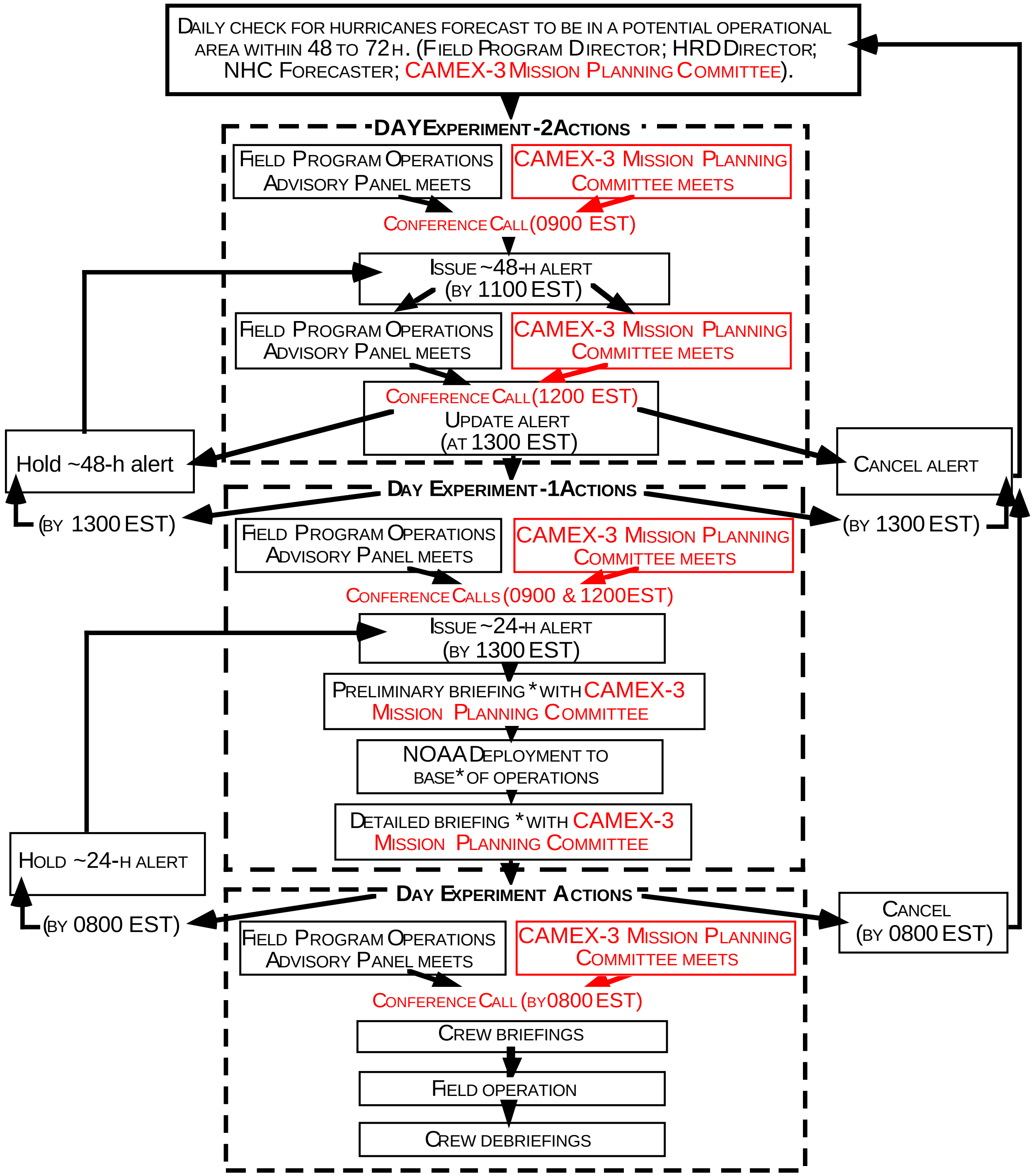
1) A research mission is determined to be probable within 72 h [field program director]. Consultation with the directors of HRD, AOC, and the CAMEX-3 Lead Mission Scientist (Hood) (or designee) determines: flight platform availability, crew and equipment status, and the type of mission(s) likely to be 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, McFadden (or AOC designee), and, the CAMEX-3 Lead Mission Scientist (or designees)] meets to discuss possible missions and operational modes (the NASA CAMEX-3 designee by conference call). Probable mission determination and approval to proceed is given by the HRD director (or designee) and the CAMEX-3 Lead Mission Scientist (or designee).

3) Primary personnel are notified by the field program director [Marks] and CAMEX-3 Lead Mission Scientist (or designee).

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, the HRD field program director, and the CAMEX-3 Principal Scientist will have telepager 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	Home phone	Work phone
H. Willoughby	HRD/Director	305-665-4080	305-361-4502
F. Marks	HRD/Field Program Director	305-271-7443	305-361-4321
P. Black	HRD/Assistant Field Program Director	305-596-4473	305-361-4320
H. Friedman	HRD/MGOC Senior Team Leader	954-962-8021	305-361-4319
J. McFadden	AOC/Project Manager for Hurricane Research	305-666-3622 813-839-7550	813-828-3310 x3076
S. White	AOC/Alternate Project Manager for Hurricane Research	813-684-7258	813-828-3310 x3072
J. Pavone	CARCAH/Liaison	305-248-3422 434-3420[1]	305-229-4474
R. Hood	CAMEX-3 Lead Mission Scientist	TBA	TBA
G. Heymsfield	TEFLUN Lead Mission Scientist	TBA	TBA
Synoptic Analysis Branch	NESDIS/Liaison		301-763-8444 301-763-8445
K. Katsaros	AOML/Director	305-361-5543	305-361-4302 305-361-4300
D. Konop	OAR/PA	301-587-3040	301-713-2483
F. Lepore	TPC/NHC/PA	305-235-6670	305-229-4404
MacDill Global[2]			813-828-3109 813-828-3356 813-828-3881

1 DSN: Defense Switched Network (replaced Autovon).
2 MacDill Global phone patch; used to contact the NOAA aircraft during missions.

Table A-2. Secondary Contacts

Name/group	Home phone	Work phone	Contacted by
HRD participants			F. Marks/MGOC
AOC participants			J. McFadden
R. McCann/AOC	813-522-3515	813-828-3310 x3125	J. McFadden
FAA			AOC
LT.COL Gale Carter 53rd Wea. Recon. Sqdn.	601-928-7681	601-377-3207 597-3207[1]	CARCAH
J. Jarrell/TPC/NHC	305-234-5389	305-229-4402	F. Marks/MGOC
C. Burr/TSAF/TPC/NHC	305-667-9932	305-229-4430	F. Marks/MGOC
Sr. Duty Meteorologist/NCEP	----	301-763-8298 301-763-8364 301-763-8076	F. Marks/MGOC
E. Walsh	303-447-1694	303-497-6357	F. Marks
W.-C. Lee/NCAR	303-939-8291	303-491-8814	F. Marks
P. Hildebrand/NCAR	303-443-6648	303-497-2050	F. Marks
S. Lord/NCEP	301-249-7713	301-763-8005	J. Franklin
C. Velden/U. Wisconsin	608-274-5500	608-262-9168	J. Franklin
J. Hallett/DRI	702-747-0776	702-677-3117 702-784-6780	R. Black
R. McIntosh/U. Massachusetts	413-256-0277	413-545-4858	P. Black
C. Swift/U. Massachusetts	413-549-0567	413-545-2136	P. Black
I. Popstefanija/Quadrant	413-549-0567	413-545-2136	P. Black
H. Selsor/NRL	504-641-5674	601-688-4760	P. Black
T. Gobel/OFCM	301-589-5771 717-637-1284	301-427-2002	P. Black
S. Chen/U. Miami	----	305-361-4048	P. Black
E. Meindl/NDBC	228-466-9529	228-688-1717	M. Powell/S. Houston
M. Burdett/NDBC	601-798-1151	228-688-2868	M. Powell/S. Houston
R. Jensen/USACE	----	601-634-2101	S. Houston
S. Gill/NOS	----	301-713-2840	S. Houston
B. Albrecht/U. Miami	305-234-5840	305-361-4045	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). However, because of operational constraints, all of the instrumentation listed in the tables may not be available on a single sortie. Any changes in instrumentation must be coordinated with AOC at the earliest possible time.

Table B-1. NOAA/AOC WP-3D (N42RF) 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
Temperature and momentum flux	Friehe radome-mounted gust probe and fast-response total temperature
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
Cloud particle charge	Particle charge probe-DRI
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)[1]
Radar reflectivity and radial velocity	Doppler X-band RHI tail (TA), 360° scan (vertical)[1]
V. **MISCELLANEOUS PARAMETERS**	
Cloud structure; surface wind	Video photography (nose, side and vertical)
Vertical atmospheric sounding	Dropsonde system
Data transmission	Aircraft-satellite-data-link (ASDL)[2]
Oceanic temperature, current and salinity profile	AXBT, AXCP, AXCTD receivers and laptop
Surface wind speed and direction and rain rate	SFMR; C-SCAT/VSDR[3]
Stable water isotope ratio	University of Houston's water collection device
Two components of electric field	DRI system
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.

3 Stepped frequency microwave radiometer and C-band scatterometer/vertically scanning Doppler radar

Table B-2. NOAA/AOC WP-3D (N43RF) instrumentation (low-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
	Temperature and momentum flux	Friehe radome-mounted gust probe and fast-response total temperature
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)[1]
	Radar reflectivity and radial velocity	Doppler X-band RHI tail (TA), 360° scan (vertical)[1]
	Radar reflectivity and radial velocity	WARDS C-band nose (NO), 180° scan (horizontal)
V.	**MISCELLANEOUS PARAMETERS**	
	Vertical atmospheric sounding	Dropsonde system
	Cloud structure; surface wind	Video photography (nose, side)
	Data transmission	Aircraft-satellite-data-link (ASDL)[2]
	Oceanic temperature profile	AXBT
	Clear-air wind s	Chaff sondes
	Surface wave spectra and altimetry	SRA[3]
	Ozone concentration	AOML O_3 instrument
VI.	**NAVIGATIONAL PARAMETERS**	
	Position, position update	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] Scanning radar altimeter

Table B-3. NASA DC-8 (NA817) instrumentation

Instrument Acronym	Instrument Type	Temporal Resolution	Spatial Resolution	Data Volume/ Mission
AMMR	Radiometer (fixed) 10-92 GHz 45° upview: 21 & 37GHz Nadir view: 18 & 37 GHz	1 Hz	~1-2 km @ surface	
ARMAR	3.8 GHz Doppler radar (Thru-nadir scanning) (multi-polarization)	1.8 s/scan; 10 MHz sample rate; 5 kHz PRF	800 m at surface; 80 m range resolution (after averaging)	10 GB (raw), 200-600 MB (processed)
CAPAC	• 2D grey probe; • Forward scattering aerosol spectrometer probe; • Passive cavity aerosol spectrometer resolution probe; • Ice crystal replicator	1 Hz	10-200 µm	2 MB at 1 Hz
DC-8 Drop	NCAR/GPS-sonde	Simultaneously track 4 sondes	10 m (vertical)	<50 KB per sonde release
JPL SAW	Microhygrometer	TBD (<0.1 s)	Single point measurement	10 MB
LASE	Differential Absorption Lidar	3 s/profile; 2 min (averaged)	*Water profiles*: 0.2 km (vert.), 5 km (horiz.), 100 m to tropopause *Relative Absorption Lidar aerosol scattering profiles*: 30 m (vert.), 200 m (horiz.), ground to 20 km	200 MB
LIP	Electric Field Mills	Conductivity:10 Hz; Waveforms: 100 kHz	~20m	30-50 MB
MACAWS	Doppler lidar (side-scanning)	Depends on PRF, scanning pattern, signal processing parameters	Horizontal coverage 2-30 km; Horizontal resolution: Line of Sight winds 150-450 m, Calculated wind vectors 1-3 km; Vertical coverage 4.2-10 km	500 MB

Table B-4. NASA ER-2 (NA809) instrumentation

Instrument Acronym	Instrument Type	Temporal Resolution	Spatial Resolution	Volume/ Mission
AMPR	Scanning radiometer (10, 19, 37, 85 GHz)	One 50-element scan every 3 s	0.6 km at 85 GHz; 1.5 km at 37 GHz; 2.8 km at 10, 19 GHz, (surface footprint)	20-30 MB
EDOP	Doppler Radar	2 Hz (~100m along-track)	Vertical: 37.5 m; Horizontal: ~1.1 km at surface and ~0.55 km at 10 km	~3.5 GB
EHAD	Dropsondes	Variable	Vertical: 5-10 s	< 1 MB
LIP	Electric Field Mills	Conductivity:10 Hz; Waveforms: 100 kHz	~20m	30-50 MB
MAMS	Scanning visible/ IR sensor	Continuous	100 m (surface) at nadir	~1 GB
MAS	Scanning spectrometer	Continuous	50 m, at nadir	5-10 GB
MIR	Scanning radiometer (89, 150, 183, 220, 325 GHz)	One scan cycle every 3 s	~1-2 km at surface	20-25 MB
NAST	Scanning interferometer and scanning microwave radiometer	Continuous	2.5 km at nadir	5-10 GB
SLS	Scanning radiometer/ spectrometer (311, 604, 637 GHz)	75 s	Vertical: ~5 km @ altitude >20 km, ~2 km @ altitude <20 km; Horizontal ~75 km	~5 MB

APPENDIX C:

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

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

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 over flight 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.

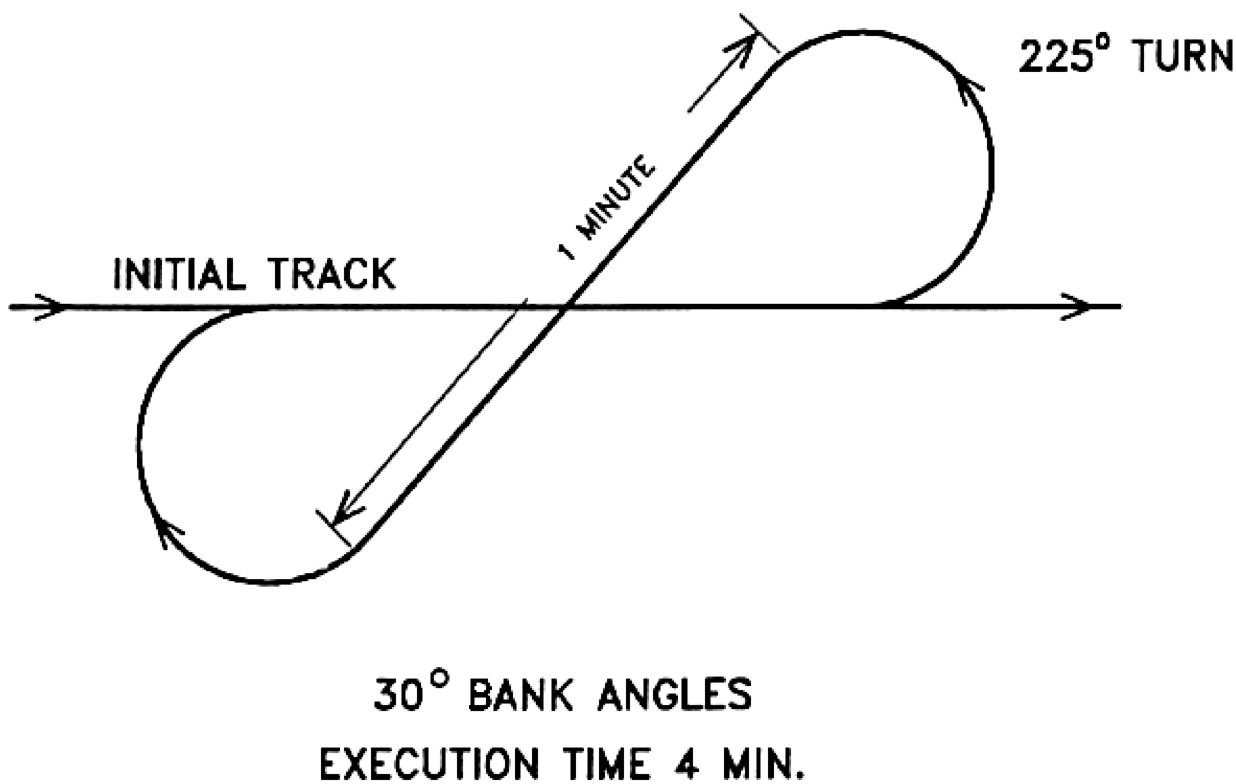


Fig. C-1 En-Route TAS calibration pattern.

C.2 Aircraft Scientific Crew Lists

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

Position	N42RF	N43RF
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, single-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	

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
SRA and C-SCAT/SFMR Scientists	E. Walsh	M. Black

Table C-2.5 Tropical Cyclone Wind fields 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
SRA Scientist	E. Walsh

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

Position	N42RF
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	N42RF	N43RF
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 and SRA Scientists	M. Black	E. Walsh

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

Position	N42RF
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: (single-option, dual-aircraft mission)

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
SRA and C-SCAT/SFMR Scientists	E. Walsh	P. Black

Table C-2.10 Clouds and Climate Study: (single-option, single-aircraft mission)

Position	N42RF
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 Over flight Locations[1]

Table C-3.1 Moored Buoys (1998)

Station Identifier	Type of Station[2]		Location Lat. (N)	Lon (W)	Area	Special Obs/ Comments[4]
44007	3D	/D	43.53	70.14	PORTLAND	A
44005*	6N	/D	42.90	68.89	GULF OF MAINE	A
44013	3D	/D	42.35	70.69	BOSTON	---
44011*	6N	/D	41.08	66.58	GEORGES BANK	A
44008*	3D	/D	40.50	69.43	NANTUCKET	A
44025[3]	3D	/D	40.25	73.17	LONG ISLAND	DW
44004*[3]	6N	/D	38.46	70.69	HOTEL	---
44009*[3]	3D	/D	38.46	74.70	DELAWARE BAY	---
44014	3D	/D	36.56	74.83	VIRGINIA BEACH	DW
41001*[3]	6N	/D	34.68	72.64	E. HATTERAS	A
41002*[3]	6N	/D	32.31	75.25	S. HATTERAS	---
41004[3]	3D	/D	32.51	79.10	EDISTO	DW
41009[3]	6N	/D	28.89	78.55	CANAVERAL EAST	---
41010	6N	/D	28.50	80.18	CANAVERAL	---
42036	3D	/D	28.51	84.51	W. TAMPA	DW
42003*[3]	10D	/V	25.94	85.91	E. GULF	A
42040	3D	/D	29.20	88.25	MOBILE SOUTH	A
42007	3D	/V	30.09	88.77	OTP	A
42001*[3]	10D	/V	25.93	89.65	MID GULF	A
42002*	10D	/V	25.89	93.57	W. GULF	A
42035	3D	/V	29.25	94.41	GALVESTON	---
42019	3D	/D	27.92	95.35	FREEPORT	---
42020	3D	/D	26.92	96.70	CORPUS CHRISTI	
41008*			31.40	80.87	GRAYS REEF	
42039	3D	/D	28.78	86.04	PENSACOLA	A

[1] Tables C-3.1 and C-3.4 were updated with information from the **Data Platform Status Report (May 8, 1998)**, NOAA/National Data Buoy Center (NDBC), Stennis Space Center, MS 39529-6000, for the period **April 30 – May 7, 1998**. (Also, the NDBC report lists the location of drifting buoys o/a **April 30 – May 7, 1998**). 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 1998), 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, 1998**); see latest edition of NDBC **Data Platform Status Report** for current status.

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

* 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 (1998)

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 (1998)

Station Identifier	Station Name	Latitude[N] Deg-min-sec	Longitude[W] Deg-min-sec
Alabama:			
EET[2]	Alabaster	33-10-42	086-46-54
79J[3]	Andalusia	31-18-00	086-23-00
ANB[2]	Anniston	33-35-26	085-50-51
BHM[2]	Birmingham	33-33-56	086-44-42
DCU[2]	Decatur	34-39-29	086-56-36
DHN[2]	Dothan	31-19-06	085-26-38
GZH[2]	Evergreen	31-25-08	087-02-53
LOR[3]	Fort Rucker	31-21-32	085-44-54
HSV[1]	Huntsville	30-44-38	095-35-10
BFM[2]	Mobile	30-36-50	088-03-48
MOB[1]	Mobile	30-41-18	088-14-44
MGM[1]	Montgomery	32-18-01	086-24-22
MSL[2]	Muscle Shoals	34-44-38	087-35-58
PAFB1[3]	Patrick AFB		
TOI[2]	Troy	31-51-27	086-00-39
TCL[2]	Tuscaloosa	33-12-43	087-36-57
Connecticut:			
BDR[1]	Bridgeport	41-09-30	073-07-44
DXR[2]	Danbury	41-22-18	073-29-04
GON0[2]	Groton/N. Lond.	41-19-39	072-02-58
HFD[2]	Hartford	41-44-06	072-39-06
HVN[2]	New Haven	41-15-53	072-53-06
IJD[2]	Willimantic	41-44-31	072-11-01
BDL[1]	Windsor Locks	41-56-17	072-40-57
Delaware:			
GED[2]	Georgetown	38-41-24	075-21-45
ILG[1]	Wilmington	39-40-22	075-36-03
Florida:			
AQQ[1]	Apalachicola	29-43-37	085-01-29
NAE[4]	Astor		
BKV[2]	Brooksville	28-28-25	082-27-16
CCAS1[2]	Cape Canaveral	28-28-34	080-34-34
NZC[4]	Cecil	30-12-44	081-52-13
CEW[2]	Crestview	30-46-20	086-31-12
CTY[1]	Cross City	29-33-00	083-06-19
DAB[1]	Daytona Beach	29-10-38	081-03-36
DTS[2]	Destin	30-23-36	086-28-03
FLL[2]	Fort Lauderdale	26-04-05	080-09-09
FXE[2]	Fort Lauderdale	26-12-00	080-11-00
FMY[2]	Fort Myers	26-35-03	081-51-45
RSW[2]	Fort Myers	26-31-37	081-45-59
FPR[2]	Fort Pierce	27-29-53	080-22-36
GNV[2]	Gainesville	29-41-31	082-16-32
HWO[2]	Hollywood	25-59-56	080-14-28
CRG[2]	Jacksonville	30-20-10	081-30-53
JAX[1]	Jacksonville	30-29-40	081-41-36
Florida *(continued)*:			
NIP[4]	Jacksonville	30-14-03	081-40-29
EYW[1]	Key West	24-33-13	081-45-13
NQX[4]	Key West	24-34-46	081-41-02
LEE[2]	Leesburg	28-49-15	081-48-35
MTH[2]	Marathon	24-43-33	081-02-52
MAI[2]	Marianna	30-50-12	085-11-01
NRB[4]	Mayport	30-23-45	081-25-21
MIA[1]	Miami	25-47-26	080-18-59
OPF[2]	Miami	25-54-36	080-16-59
TMB[2]	Miami	25-38-31	080-26-05
NDZ[4]	Milton	30-41-50	087-01-12
NFJ[4]	Milton	30-30-42	086-57-14
NSE[4]	Milton	30-44-00	087-01-00
MLB[2]	Melbourne	28-06-01	080-38-08
RRF[2]	New Port Richey	28-11-21	082-37-33
MCO[1]	Orlando	28-25-02	081-19-30
ORL[2]	Orlando	28-32-47	081-20-09
PFN[2]	Panama City	30-12-27	085-41-06
NPA[4]	Pensacola	30-21-22	087-19-24
PNS[2]	Pensacola	30-28-41	087-11-13
40J[1]	Perry-Foley	30-04-19	083-34-25
PMP[2]	Pompano Beach	26-14-44	080-06-41
PGD[2]	Punta Gorda	26-55-04	081-59-37
SRQ[2]	Sarasota/Brad.	27-24-05	082-33-31
PIE[2]	St. Peter./Clear.	27-54-44	082-41-08
TLH[1]	Tallahassee	30-23-35	084-21-12
TPA[1]	Tampa	27-57-41	082-32-25
VRB[2]	Vero Beach	27-39-18	080-24-51
PBI[1]	West Palm Beach	26-41-05	080-05-58
GIF[2]	Winter Haven	28-03-38	081-45-27
Georgia:			
ABY[2]	Albany	42-44-48	073-47-56
AMG[2]	Alma	31-32-23	082-30-27
AHN[1]	Athens	33-57-03	083-19-41
FTY[2]	Atlanta	33-46-39	084-31-28
ATL[1]	Atlanta	33-37-47	084-26-32
PDK[2]	Atlanta	33-52-42	084-17-53
AGS[1]	Augusta	33-21-52	081-57-48
DNL[2]	Augusta	33-28-01	082-02-19
SSI[2]	Brunswick	31-09-08	081-23-27
VPC[2]	Cartersville	34-07-42	084-50-50
CSG[1]	Columbus	32-30-58	084-56-32
GVL[2]	Gainesville	34-16-19	083-49-49
NBQ[4]	Kings Bay	30-47-39	081-33-25
MCN[1]	Macon	32-41-16	083-39-16
FFC[2]	Peachtree City	33-21-19	084-34-01
RMG[1]	Rome	34-20-52	085-09-40
SAV[1]	Savannah	32-07-08	081-12-08

Station Identifier	Station Name	Latitude[N] Deg-min-sec	Longitude[W] Deg-min-sec
Hawaii:			
ITO[1]	Hilo	19-43-20	155-03-21
HNL[1]	Honolulu	21-19-39	157-56-35
OGG[1]	Kahului	20-53-33	156-26-13
PHNG[4]	Kaneohe	21-27-14	157-45-56
PHBK[4]	Kekaha	22-02-11	159-47-11
LIH[1]	Lihue	21-59-02	159-20-28
MKK[1]	Molokai	21-09-28	157-05-55
PHNA[4]	Oahu	21-18-30	158-04-05
Louisiana:			
AEX[2]	Alexandria	31-20-05	092-33-31
ESF[2]	Alexandria	31-23-42	092-17-25
BTR[1]	Baton Rouge	30-32-14	091-08-49
FTPK1[3]	Fort Polk (JRTC)	31-24-18	093-18-07
FTPK3[3]	Fort Polk (JRTC)	31-07-18	093-09-22
LFT[2]	Lafayette	30-12-08	091-59-35
LCH[1]	Lake Charles	30-07-29	093-13-42
MLU[2]	Monroe	32-30-42	092-01-53
ARA[2]	New Iberia	30-01-44	091-53-04
MSY[1]	New Orleans	29-59-34	090-15-03
NBG[4]	New Orleans	29-50-14	090-01-28
NEW[2]	New Orleans	30-02-58	090-01-44
P92[1]	Salt Point	29-33-44	091-31-32
DTN[2]	Shreveport	32-32-33	093-44-41
SHV[1]	Shreveport	32-26-49	093-49-27
6R0[2]	Slidell	30-20-35	089-49-19
7R1[1]	Venice	29-15-46	089-21-48
TVR[2]	Vicks./Tallulah	32-20-53	091-01-48
Maine:			
AUG[2]	Augusta	44-18-56	069-47-50
NHZ[4]	Brunswick	43-54-01	069-56-06
CAR[1]	Caribou	46-52-02	068-00-48
FVE[2]	Frenchville	47-17-06	068-18-26
IZG[2]	Fryeburg	43-59-21	070-57-01
HUL[2]	Houlton	46-07-08	067-47-38
MLT[2]	Millinocket	45-38-52	068-41-31
PWM[1]	Portland	43-38-32	070-18-16
IWI[2]	Wiscasset	43-57-49	069-42-42
Maryland:			
NAK[4]	Annapolis	38-59-29	076-29-00
BWI[1]	Baltimore	39-10-00	076-41-00
HGR[2]	Hagerstown	39-16-52	076-36-36
N80[2]	Ocean City	38-18-30	075-07-26
NHK[4]	Patuxent River	38-16-43	076-24-50
SBY[2]	Salisbury	38-20-21	075-30-15
NUI[4]	St. Inigoes	38-08-56	076-25-12
BED[2]	Bedford	42-28-06	071-17-40
BVY	Beverly	42-35-01	070-54-59
BOS[1]	Boston	42-21-38	071-00-38
CQX[2]	Chatham	41-41-15	069-59-36
FIT	Fitchburg	42-33-07	071-45-21
Massachusetts:			
HYA[2]	Hyannis	41-40-19	070-16-11
LWM[2]	Lawrence	42-42-47	071-07-33
ACK[2]	Nantucket	41-15-14	070-03-35
EWB[2]	New Bedford	41-40-31	070-57-25
AQW[2]	North Adams	42-41-50	073-10-13
OWD[2]	Norwood	42-11-27	071-10-26
ORE[2]	Orange	42-34-18	072-16-39
PSF[2]	Pittsfield	42-25-38	073-17-21
PYM[2]	Plymouth	41-54-31	070-43-41
TAN[2]	Taunton	41-52-32	071-01-16
MVY[2]	Vineyard Haven	41-23-32	070-37-00
ORH[1]	Worcester	42-16-14	071-52-23
Mississippi:			
BIX1[4]	Biloxi	30-24-07	088-55-04
BIX2[4]	Biloxi	30-24-34	088-55-08
BIX3[4]	Biloxi	30-24-36	088-55-09
GLH[2]	Greenville	33-29-38	090-58-52
GWO[2]	Greenwood	33-29-33	090-05-01
GPT[2]	Gulfport	30-24-43	089-04-51
HBG[2]	Hattiesburg	31-16-10	089-15-22
HKS[2]	Jackson	32-20-14	090-13-18
JAN[1]	Jackson	32-19-11	090-04-39
MCB[2]	McComb	31-10-55	090-28-20
MEI[1]	Meridian	32-20-17	088-44-52
NMM[4]	Meridian	32-32-47	088-32-35
NJW[4]	Meridian Rng.-B	32-47-39	088-49-58
PQL[2]	Pascagoula	30-27-49	088-31-55
TUP[1]	Tupelo	34-15-39	088-46-16
New Hampshire:			
BML[2]	Berlin	44-34-34	071-10-43
CON[1]	Concord	43-11-43	071-30-04
AFN[2]	Jaffrey	42-48-21	072-00-02
LEB[2]	Lebanon	43-37-38	072-18-21
MHT[2]	Manchester	42-55-45	071-26-09
6B1[2]	Rochester	43-16-41	070-55-20
HIE[2]	Whitefield	44-21-58	071-33-09
New Jersey:			
12N[1]	Andover	41-00-32	074-44-12
ACY[1]	Atlantic City	39-27-53	074-35-12
CDW[2]	Caldwell	40-52-35	074-16-59
MIV[2]	Millville	39-21-58	075-04-42
VAY[2]	Mount Holly	39-56-26	074-50-28
EWR[1]	Newark	40-40-57	074-10-10
N52[2]	Somerville	40-37-26	074-40-10
FWN[2]	Sussex	41-11-57	074-37-34
TEB[1]	Teterboro	40-51-32	074-03-24
TTN[2]	Trenton	40-16-35	074-48-59
ALB[1]	Albany	42-44-48	073-47-56
BGM[1]	Binghamton	42-12-28	075-58-53
BUF[1]	Cheektowaga	42-56-27	078-44-09

Station Identifier	Station Name	Latitude[N] Deg-min-sec	Longitude[W] Deg-min-sec
New Jersey *(continued)*:			
DSV[2]	Dansville	42-34-10	077-42-52
DKK[2]	Dunkirk	42-29-35	079-16-33
ELM[2]	Elmira	42-09-23	076-54-10
FRG[2]	Farmingdale	40-44-03	073-25-01
N00[2]	Fulton	43-20-59	076-23-05
GFL[2]	Glens Falls	43-20-17	073-36-38
ISP[2]	Islip	40-47-38	073-06-06
MSS[2]	Massena	44-55-59	074-50-57
MTP[1]	Montauk	41-04-23	071-55-24
MGJ[2]	Montgomery	41-30-33	074-15-54
NYC[1]	New York City	40-47-00	073-58-00
JFK[1]	New York City	40-38-19	073-45-44
LLGA[1]	New York City	40-46-45	073-52-48
PEO[2]	Penn Yan	42-38-35	077-02-58
PLB[2]	Plattsburgh	44-40-56	073-31-40
POU[2]	Poughkeepsie	41-37-32	073-52-55
ROC[1]	Rochester	43-07-00	077-40-36
SLK[2]	Saranac Lake	44-23-35	074-12-10
HWV[2]	Shirley	40-49-18	072-52-08
SYR[1]	Syracuse	43-06-33	076-06-12
UCA[2]	Utica	43-08-37	075-23-04
ART[2]	Watertown	43-59-20	076-01-35
ELZ[2]	Wellsville	42-06-27	077-59-04
FOK[2]	Westhampton Bch.	40-51-03	072-37-14
HPN[2]	White Plains	41-03-43	073-42-16
North Carolina:			
AVL[1]	Asheville	35-25-55	082-32-15
NLT[4]	Atlantic	34-52-45	076-20-10
MRH[2]	Beaufort	34-43-57	076-39-25
IGX[4]	Chapel Hill	35-56-00	079-03-51
CLT[1]	Charlotte	35-12-48	080-56-55
NKT[4]	Cherry Point	34-53-52	076-52-51
NIS[4]	Cherry Point	34-53-11	076-51-47
ECG[2]	Elizabeth City	36-15-47	076-10-58
FAY[2]	Fayetteville	34-59-22	078-52-48
GSO[1]	Greensboro	36-05-51	079-56-37
HSE[1]	Hatteras	35-13-56	075-37-21
HKY[2]	Hickory	35-44-32	081-22-56
NCA[4]	Jacksonville	34-42-21	077-26-27
LBT[2]	Lumberton	34-36-26	079-03-36
MEB[2]	Maxton	34-47-29	079-22-05
EQY[2]	Monroe	32-30-42	092-01-53
EWN[2]	New Bern	35-04-03	077-02-50
NBT[4]	Piney Island	35-01-20	076-27-45
RDU[1]	Raleigh/Durham	35-52-14	078-47-11
RZZ[2]	Roanoke Rapids	36-26-22	077-42-35
RWI[2]	Rocky Mt.-Wilson	35-50-58	077-53-48
NJM[4]	Swansboro	34-41-34	077-01-46
ILM[1]	Wilmington	34-16-06	077-54-22
INT[2]	Winston Salem	36-08-00	080-13-29

Station Identifier	Station Name	Latitude[N] Deg-min-sec	Longitude[W] Deg-min-sec
Pennsylvania:			
ABE[1]	Allentown	40-39-03	075-26-57
AOO[2]	Altoona	40-18-00	078-19-01
BFD[2]	Bradford	41-47-55	078-38-09
N97[2]	Clearfield	41-02-48	078-24-42
N88[2]	Doylestown	40-19-48	075-07-21
ERI[1]	Erie	42-04-48	080-10-57
CXY[2]	Harrisburg	40-13-06	076-51-20
JST[2]	Johnstown	40-18-53	078-49-51
LNS[2]	Lancaster	40-07-13	076-17-40
2G6[2]	Meadville	41-37-33	080-12-44
PHL[1]	Philadelphia	39-52-06	075-13-52
PNE[1]	Philadelphia	40-04-44	075-00-49
AGC[2]	Pittsburgh	40-21-17	079-55-18
PIT[1]	Pittsburgh	40-30-14	080-15-59
PTW[2]	Pottstown	40-14-18	075-33-26
SEG[2]	Selinsgrove	40-49-09	076-51-58
AVP[1]	Wilkes-Barre/Scran.	41-20-20	075-43-36
IPT[1]	Williamsport	41-14-36	076-55-18
NXX[4]	Willow Grove	40-11-35	075-08-40
THV[2]	York	39-55-10	076-52-37
Rhode Island:			
UUU[2]	Newport	41-31-48	071-17-01
PVD[1]	Providence	41-43-19	071-25-57
WST[2]	Westerly	41-20-59	071-47-56
South Carolina:			
AND[2]	Anderson	34-29-52	082-42-35
NBC[4]	Beaufort	32-29-37	080-42-11
CHS[1]	Charleston	32-53-56	080-02-26
CEU[2]	Clemson	34-40-20	082-52-53
CUB[2]	Columbia	33-58-15	080-59-40
CAE[1]	Columbia	33-56-31	081-07-05
FLO[2]	Florence	34-11-16	079-43-51
GSP[1]	Greer	34-53-02	082-13-15
GMU[2]	Greenville	34-50-46	082-20-46
GRD[2]	Greenwood	34-14-50	082-09-17
CRE[2]	Myrtle Bch. N.	33-48-58	078-43-14
NEXC[4]	Navelexcen		
OGB[2]	Orangeburg	33-27-50	080-51-13
29J[2]	Rock Hill	34-59-02	081-03-21
Texas:			
ABI[1]	Abilene	32-24-37	099-40-54
ALI[2]	Alice	27-44-28	098-01-29
AMA[1]	Amarillo	35-13-12	101-43-02
LBX[2]	Angle./Lk. Jack.	29-06-55	095-27-47
F54[2]	Arlington	32-39-50	097-05-45
AUS[1]	Austin	30-17-26	097-41-45
BPT[1]	Beau.t/Pt. Arth.	29-57-06	094-01-34
BSM[2]	Bergstrom		
BGD[2]	Borger	35-41-42	101-23-42

Station Identifier	Station Name	Latitude[N] Deg-min-sec	Longitude[W] Deg-min-sec
Texas *(continued)*:			
BRO[1]	Brownsville	25-54-51	097-25-23
BMQ[2]	Burnet	30-44-26	098-14-07
CDS[2]	Childress	34-25-39	100-17-00
CLL[2]	College Station	30-34-56	096-21-42
CXO[2]	Conroe	30-21-24	095-24-50
CRP[1]	Corpus Christi	27-46-23	097-30-46
NGP[4]	Corpus Christi	27-41-19	097-17-30
NGW[4]	Corpus Christi	27-43-21	097-26-33
NVT[4]	Corpus Christi	27-37-52	097-18-42
CRS[2]	Corsicana	32-01-52	096-23-56
COT[2]	Cotulla	28-27-12	099-13-01
DHT[2]	Dalhart	36-01-16	102-32-52
DAL[2]	Dallas	32-51-09	096-51-20
RBD[2]	Dallas	32-40-33	096-51-50
DFW[1]	Dallas/Fort Worth	32-53-49	097-01-19
DRT[1]	Del Rio	29-22-29	100-55-25
DTO[2]	Denton	33-12-22	097-11-56
6R6[1]	Dryden	30-02-53	102-12-47
ELP[1]	El Paso	31-48-40	106-22-33
FST[2]	Fort Stockton	30-54-43	102-55-00
AFW[2]	Fort Worth	32-58-24	097-19-05
FTW[2]	Fort Worth	32-49-31	097-21-51
NFW[4]	Fort Worth	32-45-57	097-26-00
GLS[2]	Galveston	29-16-13	094-51-51
GDP[1]	Pine Springs	31-49-52	104-48-32
HRL[2]	Harlingen	26-13-47	097-39-19
HDO[2]	Hondo	29-21-34	099-10-27
DWH[2]	Houston	30-04-03	095-33-22
IAH[1]	Houston	29-59-33	095-21-50
TO2[2]	Houston	29-31-08	095-14-30
UTS[2]	Huntsville	30-44-38	095-35-10
JCT[1]	Junction	30-30-39	099-45-59
NQI[4]	Kingsville	27-30-11	097-48-42
DLF[3]	Laughlin		
GGG[2]	Longview	32-23-26	094-42-50
LBB[1]	Lubbock	33-40-03	101-49-17
LFK[2]	Lufkin	31-14-01	094-45-00
MFE[2]	McAllen	26-10-47	098-14-40
TKI[2]	McKinney	33-11-06	096-35-16
NMT[4]	McMullen		
MAF[1]	Midland	31-56-52	102-12-31
MWL[2]	Mineral Wells	32-46-56	098-03-41
3R5[2]	New Braunfels	29-42-31	098-02-43

[1] NWS = National Weather Service site
[2] FAA = Federall Aviation Admisnistration site
[3] DODa = Department of Defence (Air Force) site
[4] DODn= Department of Defence (Navy) site

Station Identifier	Station Name	Latitude[N] Deg-min-sec	Longitude[W] Deg-min-sec
Texas (continued):			
E02[2]	Odessa	31-55-17	102-23-30
NOG[4]	Orange Grove	27-53-21	098-02-39
GDP[1]	Guadalupe Pass		
T31[2]	Port Isabel	26-09-33	097-20-15
RKP[2]	Rockport	28-05-01	097-02-47
SJT[1]	San Angelo	31-21-05	100-29-38
SAT[1]	San Antonio	29-31-58	098-27-49
SSF[2]	San Antonio	29-20-20	098-28-18
P07[1]	Sanderson	MISSING	
SAT[1]	San Antonio	29-31-58	098-27-49
SSF[2]	San Antonio	29-20-20	098-28-18
P07[1]	Sanderson	MISSING	
TRL[2]	Terrel	32-42-49	096-16-06
TYR[2]	Tyler	32-21-31	095-24-14
VCT[1]	Victoria	28-51-45	096-55-47
ACT[1]	Waco	31-37-02	097-13-40
SPS[1]	Wichita Falls	33-58-43	098-29-34
INK[2]	Wink	31-46-49	103-12-03
Virginia:			
DAN[2]	Danville	36-34-22	079-20-07
NFE[4]	Fentress	36-42-03	076-07-42
LYH[1]	Lynchburg	37-19-15	079-12-24
PHF[2]	Newport News	37-07-56	076-29-40
NGU[4]	Norfolk	36-56-01	076-17-45
ORF[1]	Norfolk	36-54-13	076-11-31
NYG[4]	Quantico	38-30-45	077-17-30
RIC[1]	Richmond	37-30-40	077-19-24
ROA[1]	Roanoke	37-19-01	079-58-27
NTU[4]	Virginia Beach	36-49-16	076-01-42
AKQ[1]	Wakefield	36-58-53	077-00-04
WAL[1]	Wallops Island	37-56-26	075-27-47
DCA[1]	Washington, DC	38-50-54	077-02-03
IAD[1]	Washington, DC	38-56-05	077-26-51
	CARIBBEAN		
Puerto Rico:			
TJNR[4]	Roosevelt Roads	18-15-19	065-38-19
TSJU[1]	San Juan	18-26-05	066-00-40
Virgin Islands:			
STT[2]	Charlotte Amalie	18-20-18	064-58-44
STX[2]	Christiansted	17-42-03	064-48-24

Table C-3.4 C-MAN sites (1998)[1]

Station Identifier	Station Name/ Payload Type	Location		Area	Comments[3]	Height (m)
		Lat. (N)	Lon (W)			
MDRM1*[2]	Mt. Desert Rock, ME/D	43.97	68.13	ME COAST	---	22.6
MISM1*	Matinicus Rock, ME/D	43.78	68.86	ME COAST	---	16.5
IOSN3*	Isle of Shoals, NH/D	42.97	70.62	NH COAST	---	19.2
BUZM3*[2]	Buzzards Bay, MA/V	41.40	71.03	MA COAST	A	24.8
ALSN6*[2]	Ambrose Light, NY/V	40.46	73.83	NY COAST	---	49.1
TPLM2*	Thomas Point, MD/V	38.90	76.44	MD COAST	---	18.0
CHLV2*[2]	Chesapeake Light, VA/D	36.90	75.71	VA COAST	A	43.3
DUCN7*[2]	Duck Pier, NC/V	36.18	75.75	NC COAST	A	20.4
DSLN7*[2]	Diamond Shoals Light, NC/D	35.15	75.30	NC COAST	A, DP	46.6
CLKN7*	Cape Lookout, NC/V	34.62	76.52	NC COAST	A	9.8
FPSN7*	Frying Pan Shoals, NC/D	33.49	77.59	NC COAST	A	44.2
FBIS1*	Folly Island, SC/D	32.68	79.89	SC COAST	A	9.8
SPGF1*	Settlement Point, GBI/V	26.70	78.99	GR BAHAMA	A	9.8
SAUF1*	St. Augustine, FL/V	29.86	81.26	FL COAST	A	16.5
LKWF1*	Lake Worth, FL/V	26.61	80.03	FL COAST	A	13.7
FWYF1	Fowey Rocks, FL/V	25.59	80.10	FL COAST	A	43.9
MLRF1*	Molasses Reef, FL/V	25.01	80.38	FL COAST	---	15.8
SMKF1*	Sombrero Key, FL/V	24.63	81.11	FL COAST	---	48.5
SANF1	Sand Key, FL/V	24.46	81.88	FL COAST	A	13.1
LONF1	Long Key, FL/V	24.84	80.86	FL COAST	---	7.0
DRYF1	Dry Tortugas, FL/V	24.64	82.86	FL COAST	---	5.7
VENF1*[2]	Venice, FL/V	27.07	82.45	FL COAST	A	11.6
CDRF1	Cedar Key, FL/V	29.14	83.03	FL COAST	A	10.1
CSBF1*	Cape San Blas, FL/V	29.67	85.36	FL COAST	A	9.8
KTNF1	Keaton Beach, FL/V	29.82	83.59	FL COAST	A	10.1
DPIA1*[2]	Dauphin Island, AL/V	30.25	88.07	AL COAST	---	17.4
BURL1*	Southwest Pass, LA/D	28.90	89.43	LA COAST	A	30.5
GDIL1*	Grand Isle, LA/V	29.27	89.96	LA COAST	A	15.8
SRST2*	Sabine, TX/V	29.67	94.05	TX COAST	A	12.5
PTAT2*	Port Aransas, TX/V	27.83	97.05	TX COAST	A	14.9

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 Note remarks section of NDBC report (**May 1, 1998**); see latest edition of NDBC **Data Platform Status Report** for current status.

3 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 (1998)*

Station Name	Location Lat. (N)	Location Lon (W)
Bermuda Pier, St. Georges Island	32.37	64.70
Eastport Bay, ME	44.90	66.98
Bergen Point West, NY	40.63	74.14
Solomons Island, MD	38.32	76.45
Kiptopeke, VA	37.17	75.98
Lewisetta, Potomac River, VA	37.99	76.45
Sewells Point, VA	36.97	76.32
Chesapeake Bay Bridge, VA	36.97	76.10
Duck, FRF Pier, NC	36.18	75.74
Cape Hatteras Fishing Pier, NC	35.22	75.63
Mayport, FL	30.39	81.42
St. Augustine Beach, FL	29.85	81.25
Virginia Key, FL	25.72	80.15
Naples, FL	26.12	81.80
Port Manatee, Tampa Bay, FL[1]	27.63	82.55
St. Petersburg, FL	27.75	82.62
Port Tampa, FL[1]	27.90	82.60
McKay Bay, FL[1]	27.90	82.42
Clearwater Beach, FL	27.97	82.42
Apalachicola Bay, FL	29.72	85.00
Panama City Beach, FL	30.20	85.87
Morgans Point, TX	29.47	94.92
Eagle Point, TX	29.35	94.77
Port Bolivar, TX	29.30	94.79
Galveston Pier, TX	29.28	94.78
Galveston (offshore), TX	29.12	94.50
Freeport, TX	28.94	95.30
Corpus Christi, TX	27.57	97.22
Port Mansfield, TX	26.55	97.42
Cochino Pequeno	15.85	86.50

* Quality controlled data from these platforms can be obtained from NDBC's **Seaboard Bulletin Board Service** soon after the fact. For information contact NDBC or Sam Houston at (305) 361-4509.

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

C.4 NWS and DOD Locations/Contacts - 1998

Table C-4.1 DOD RAWIN/RAOB locations/contacts

Station Identifier	Address/Location	Sqdrn. Co/Fac. Cmdr.		Telephone Numbers
COF (74795)	45th Wea. Squadron/CC 1201 Minuteman Street Patrick AFB, FL 32925-3238	Col. David Urbanski Squadron Commander Lt. Col. Dewey Harms Chief of Systems	 FAX: DNS[1]: FAX:	407-494-7012 407-494-7426 407-854-7426 407-853-4315 853-8211 407-853-8295
VPS (72221)	46th OSS/OSW 601 W. Choctawhatchee Suite 60 Eglin AFB, FL 32542-5719	Lt. Col. Robert Lafbare Squadron Commander Joe Kerwin Chief, Range Support	 DSN[1]: FAX:	850-882-5449 850-882-4800 850-882-5224 850-882-5960 850-872-5323 872-5323 850-882-3341
TXKF[2] (78016)	P.O. Box 123 St. Georges Bermuda GEBX	Mr. Roger Williams	 FAX:	441-293-5339 441-293-5078 441-293-6658

1 DSN: Defense Switched Network.

2 The facility at Bermuda is not military. Mr. Roger Williams is the manager of the meteorology office.

Note 1: AT&T can be used to call Bermuda from HRD/AOML; however, you must have an AT&T FTS 2000 credit card (see Gladys Medina if you need an AT&T FTS 2000 credit card for official business).

To place a call using an AT&T FTS 2000 card:
(a) Follow instructions on the back of your AT&T FTS 2000 credit card.
(b) Division secretaries or Gladys Medina can assist placing calls.

Note 2: In recent years, CSR operated the meteorological station at Antigua under a contract with the USAF. Meteorological operations at Antigua were terminated May 1, 1993. During the 1998 field program, if additional rawinsonde/radiosonde data from the eastern Caribbean area are required, the MGOC representative should contact the Meteorological Office, Saint Martin (Saint Maarten), Netherlands Antilles [TNCM (78866)]. Petier Trappenberg is the Director of the facility. He can be contacted as follows:

AT&T: 011-599-9-683933 (FAX: 011-599-9-683999)

For further information or assistance, contact Albert Mongeon (NWS) at 301-713-0882, ext. 140.

Note 3: Additional rawinsondes/radiosondes from DOD rawinsonde sites, including Patrick AFB, Eglin AFB, and NAS Guantanamo (Cuba), can be requested through the CARCAH at TPC/NHC (see Appendix F, section F.3, 3g)].

Note 4: When requesting additional RAWINs/RAOBs from any DOD or other facility, the MGOC representative should:

(a) State the beginning and ending date(s) and time(s) [UTC].
(b) Specify the desired frequency of rawinsondes/radiosondes (3-, 6-, or 12-hourly intervals).
(c) State that rawinsondes/radiosondes should be "flown" (at least) to the 100-mb level.
(d) Request that all data (*i.e.,* raw data **and** worked-up soundings) be sent to Howard A. Friedman, AOML/HRD, 4301 Rickenbacker Causeway, Miami, Florida, 33149.

Table C-4.2 NWS/Eastern Region RAWIN/RAOB locations/contacts[1]

Station Identifier	Address/Location	MIC/OIC	Telephone Numbers
CHS (72208)	NWS/WSO, NOAA 5777 S. Aviation Avenue Charleston, SC 29406	Steve Rich MIC	803-744-0303 803-744-0211 803-727-4395 FAX: 803-747-5405
GSO (72317)	NWS/WSO, NOAA 6425 Airport Parkway Greensboro, NC 27409	Johnnie M. Smith OIC	336-668-9269
MHX (72305)	NWS/WSO, NOAA 53 Roberts Road Newport, NC 28570	Thomas Kriehn MIC	919-223-5122 919-223-5631 919-223-2328 FAX: 919-223-3673 1-800-697-7374
OKX (72501)	NWS/WSFO, NOAA 175 Brookhaven Avenue c/o Brookhaven Nat'l. Lab. Upton, NY 11973	Michael E. Wylie MIC	516-924-0517 516-924-0037 FAX: 516-924-0519
WAL (72402)	NWS/WSCMO[2,3] Building N162 Wallops Island, VA 23337	Sam West Chief, UA Section	757-824-1586 FAX: 757-824-2414
	Weather Office[3,4] Building E106 Wallops Island, VA 23337	Ted Wilz[5] MIC	757-824-1325 757-824-1638 FAX: 757-824-2410

1 Additional rawinsondes or radiosondes may be requested from the NWS/ER or NWS/SR stations listed in Tables C-4.2 and C-4.3: (a) via AFOS [contact NHC's Communications Unit personnel for assistance]; (b) through the duty Hurricane Specialist (NHC); or (c) directly by phone. Messages sent via AFOS should contain a statement asking that the appropriate NWS station(s) acknowledge and confirm each request. Remember to identify the program as "**HRD/Hurricane Field Program**" and follow instructions in Note 4, at the bottom of Table C-4.1.

2 Normal hours of operation: 0600-2230 EDT (or EST, when appropriate).

3 If you can't reach your party on any of the numbers shown, contact the NASA switchboard operator (757-824-1000) and ask to have your party paged.

4 Normal hours of operation: 0530-1600 EDT (or EST, when appropriate).

5 Home phone number is 410-860-2108.

Table C-4.3 NWS/Southern Region RAWIN/RAOB locations/contacts[1]

Station Identifier	Address/Location	MIC/OIC	Telephone Numbers
BMX (72230)	NWS/WSO, NOAA 465 Weathervane Road Alabaster, AL 35007-5079	Gary S. Petti MIC	205-664-7828 205-664-7829 205-664-7830 205-664-3010 FAX: 205-664-7821
BRO (72250)	NWS/WSO, NOAA 20 South Vermillion Road Brownsville, TX 78521-5798	Richard R. Hagan MIC	956-504-3084 956-504-3354 956-504-1432 956-504-3184 956-504-1631 FAX: 956-982-1766
CRP (72251)	NWS/WSO, NOAA International Airport 300 Pinson Drive Corpus Christi, TX 78406-1803	Joe Arellano, Jr. MIC	512-299-1353 512-299-1354 512-289-0959 FAX: 512-289-7823
DRT (72261)[2]	NWS/WSO, NOAA Weather Station Road International Airport Del Rio, TX 78840	Vacant	830-774-9642
EYW (72201)[3]	NWS/WSO, NOAA International Airport 3491 S. Roosevelt Blvd. Key West, FL 33040-5234	Bobby McDaniel MIC (Home telephone: 305-872-7303)	305-295-1324 305-295-1316 FAX: 305-293-9987 *(call ahead)*
FFC (72215)	NWS/WSMO, NOAA 4 Falcon Drive Peachtree City, GA 30269	Carlos Garza MIC	770-486-1133 770-486-1333 770-486-0026 770-486-0027 FAX: 770-486-9333
FWD (72249)	NWS/WSFO, NOAA 3401 Northern Cross Blvd. Forth Worth, TX 76137-3610	Gifford "Skip" Ely MIC	817-831-1581 817-831-1157 817-831-1574 817-831-1595 FAX: 817-831-3025
JAN (72235)	NWS/WSFO, NOAA 234 Weather Service Drive Jackson, MS 39208	Tice H. Wagner, III MIC	601-965-4639 601-965-4638 601-939-2786 601-936-2189 FAX: 601-965-4028
JAX (72206)	NWS/WSO, NOAA 13701 Fang Drive Jacksonville, FL 32218	Stephen M. Letro MIC	904-741-4370 904-741-4411 904-741-5186 FAX: 904-741-0078

Table C-4.3 NWS/Southern Region RAWIN/RAOB locations/contacts[1] (continued)

Station Identifier	Address/Location	MIC/OIC		Telephone Numbers
LCH (72240)	NWS/WSO, NOAA 500 Airport Blvd., #115 Lake Charles, LA 70607-0668	Steve Rinard MIC	 FAX:	318-477-3422 318-477-2495 318-477-0354 318-474-8705
LZK (72340)	NWS/WSO, NOAA N. Little Rock Airport 8400 Remount Road N. Little Rock, AR 72118	Renee Fair MIC	 FAX:	501-834-9102 501-834-3955 501-834-0308 501-834-0715
MFL (72203)	NWS/WSMO, NOAA 11691 S.W. 17th Street Miami, FL 33165-2149	Paul J. Hebert MIC (New MIC to be named after 3 July 1998)	 FAX: FAX:	305-229-4500 305-229-4501 305-229-4523 305-229-4528 305-229-4553 305-559-4503
SHV (72248)	NWS/WSO, NOAA 5655 Hollywood Avenue Shreveport, LA 71109-7750	Lee Harrison MIC	 FAX:	318-635-9398 318-636-7345 318-636-4594 318-635-8734 318-636-9620
SIL (72233)	NWS/WSFO, NOAA 62300 Airport Road Slidell, LA 70460-5243	Paul S. Trotter MIC	 FAX:	504-649-0429 504-589-2808 504-649-0357 504-645-0565 504-649-2907
TBW (72210)	NWS/WSO, NOAA 2525 14th Avenue, S.E. Ruskin, FL 33570 [Tampa Bay Area]	Ira Brenner MIC	 FAX: FAX:	813-641-2512 813-645-4111 813-641-1720 813-641-1807 813-641-2441 813-641-2619
SJU (78526)	NWS/WSFO, NOAA 4000 Carretera 190 Carolina, PR 00979	Israel Matos[5] MIC Rafael Mojica WCM	 UA:[4] FAX:	787-253-4501 787-253-4504 787-253-4587 787-253-7802
TLH (72214)	NWS/WSO, NOAA Regional Airport 330 Capital Circle, S.W. Suite 227 Tallahassee, FL 32310-8723	Paul Duval MIC	 FAX:	850-942-8398 850-942-9394 850-942-9636

1 See footnote 1 in Table C-4.2.
2 Hours: 0400-2000 CDT (or CST, when appropriate).
3 If unable to contact MIC, further information is available from the Miami WSFO.
4 UA: Upper air station.
5 Pager: 1-800-652-0608

Table C-4.4 NWS/Eastern Region coastal radar locations/contacts

Station Identifier/ Type Radar/ Lat./Lon.	Address/Location	MIC/OIC	Telephone Numbers
AKQ (-----)/ WSR-88D 37.0°N/ 77.47°W	NWS/WSO, NOAA 1009 General Mahone Hwy. Wakefield, VA 23888	Anthony Siebres MIC	757-899-5730 757-899-4200 FAX: 757-899-3605
CHS (72208)/ WSR-88D/ 32.66°N/ 81.04°W	NWS/WSO, NOAA 5777 S. Aviation Avenue Charleston, SC 29406	Stephen T. Rich MIC	803-744-0303 803-744-0211 803-727-4395 FAX: 803-747-5405
ILM (72301)/ WSR-88D Net 33.99°N/ 78.43°W	NWS/WSO, NOAA 2015 Gardner Drive Wilmington, NC 28405	Richard W. Anthony MIC	910-763-8331 910-762-4289 910-762-9476 FAX: 910-762-1288
MHX (72305)/ WSR-88D/ 34.46°N/ 76.52°W	NWS/WSO, NOAA 53 Roberts Road Newport, NC 28570	Thomas Kriehn MIC	919-223-5122 919-223-5631 919-223-2328 FAX: 919-223-3673
OKX (72501)/ WSR-88D/ 41.86°N/ 72.86°W	NWS/WSO, NOAA 175 Brookhaven Avenue c/o Brookhaven Nat'l. Lab. Upton, NY 11973	Michael E. Wyllie MIC	516-924-0517 516-924-0037 FAX: 516-924-0519

Note 1: NWS/ER official contact for WSR-88D information is Laurie Hermes (W/ER/ERH), WSR-88D meteorologist (516-244-0143).

Table C-4.5 NWS/Southern Region coastal radar locations/contacts

Station Identifier/ Type Radar/ Lat./Lon.	Address/Location	MIC/OIC	Telephone Numbers
BRO (72250)/ WSR-88D/ 25.92°N/ 97.55°W	NWS/WSO, NOAA 20 South Vermillion Road Brownsville, TX 78521-6851	Richard R. Hagan MIC	956-504-3084 956-504-3354 956-504-3184 956-504-1631 FAX: 956-982-1766
CRP (72251)/ WSR-88D 27.81°N/ 97.15°W	NWS/WSO, NOAA International Airport 300 Pinson Drive Corpus Christi, TX 78406	Joe Arellano, Jr. MIC	512-289-1353 512-289-1354 512-289-1357 FAX: 512-289-7823
EYW (72201)/ WSR-88D/ (at KBYX) 24.60°N/ 81.70°W	NWS/WSO, NOAA International Airport 3491 S. Roosevelt Blvd. Key West, FL 33040-5234	Bobby McDaniel MIC (Home telephone: 305-872-7303)	305-295-1324 305-295-1316 FAX: 305-293-9987 *(call ahead)*
HGX (72242)/ WSR-88D/ 29.47°N/ 95.09°W	NWS/WSO, NOAA 1620 Gill Road Dickinson, TX 77539	William "Bill" Read MIC	281-337-5192 281-337-5285 281-534-2157 281-534-5625 FAX: 281-337-3798
JAX (72206)/ WSR-88D 30.48°N/ 81.70°W	NWS/WSO, NOAA 13701 Fang Drive Jacksonville, FL 32218	Stephen M. Letro MIC	904-741-4411 904-741-5186 FAX: 904-741-0078
LCH (72240)/ WSR-88D 30.13°N/ 93.22°W	NWS/WSO, NOAA 500 Airport Boulevard, #115 Lake Charles, LA 70605	Steve Rinard MIC	318-477-3422 318-477-2495 318-477-0354 FAX: 318-474-8705
LIX (72233)/ WFSR-88D (at KNEW) 30.34°N/ 89.83°W	NWS/WSFO, NOAA 62300 Airport Road Slidell, LA 70460	Paul S. Trotter MIC	504-649-0984 504-649-0429 504-589-2808 504-649-0899 504-645-0565 FAX: 504-649-2907

Table C-4.5 NWS/Southern Region coastal radar locations/contacts (continued)

Station Identifier/ Type Radar/ Lat./Lon.	Address/Location	MIC/OIC	Telephone Numbers	
MIA (72203)/ WSR-88D (at KAMX)/ 25.61°N/ 80.41°W	NWS/WSFO/NOAA 11691 S.W. 17th Street Miami, FL 33165-2149	Paul J. Hebert MIC (New MIC to be named after 3 July 1998)	 FAX:	305-229-4500 305-229-4501 305-229-4520 305-229-4528 305-229-4553 305-559-4503
MLB (-----)/ WSR-88D/ 28.78°N/ 80.93°W	NWS/WSO, NOAA 421 Croton Road Melbourne, FL 32935	Bart Hagemeyer MIC	 FAX:	407-254-6083 407-254-6923 407-259-7589 407-259-7618 407-255-0791
MOB (72223)/ WSR-88D/ 30.68°N/ 88.24°W	NWS/WSO, NOAA 8400 Airport Boulevard Mobile, AL 36608	Randall McKee MIC	 FAX:	334-633-0921 334-633-7342 334-633-6443 334-633-2471 334-607-9773
TBW (72210)/ WSR-88D/ 28.00°N/ 82.42°W	NWS/WSO, NOAA 2525 14th Avenue, S.E. Ruskin, FL 33570 [Tampa Bay Area]	Ira Brenner MIC	 FAX:	813-645-4111 813-641-2512 813-641-1720 813-641-2619 813-641-2441
TJUA(-----)/ WSR-88D/ 18.02°N/ 66.08°W	NWS/WSFO, NOAA 4000 Carretera 190 Carolina, PR 00979	Israel Matos MIC Rafael Mojica WCM	 FAX:	787-253-4501 787-253-4504 787-253-4502 787-253-7802
TLH (72214) WSR-88D/ 30.40°N/ 84.33°W	NWS/WSO, NOAA Regional Airport 3300 Capital Circle, S.W. Suite 227 Tallahassee, FL 32310-8723	Paul Duval MIC	 FAX:	850-942-8398 850-942-9394 850-942-9395 850-942-9396

Note 1: NWS/SR official contact for WSR-88D information is Victor Murphy (W/SR/SRH), WSR-88D Meteorologist (817-978-2367 ext. 130).

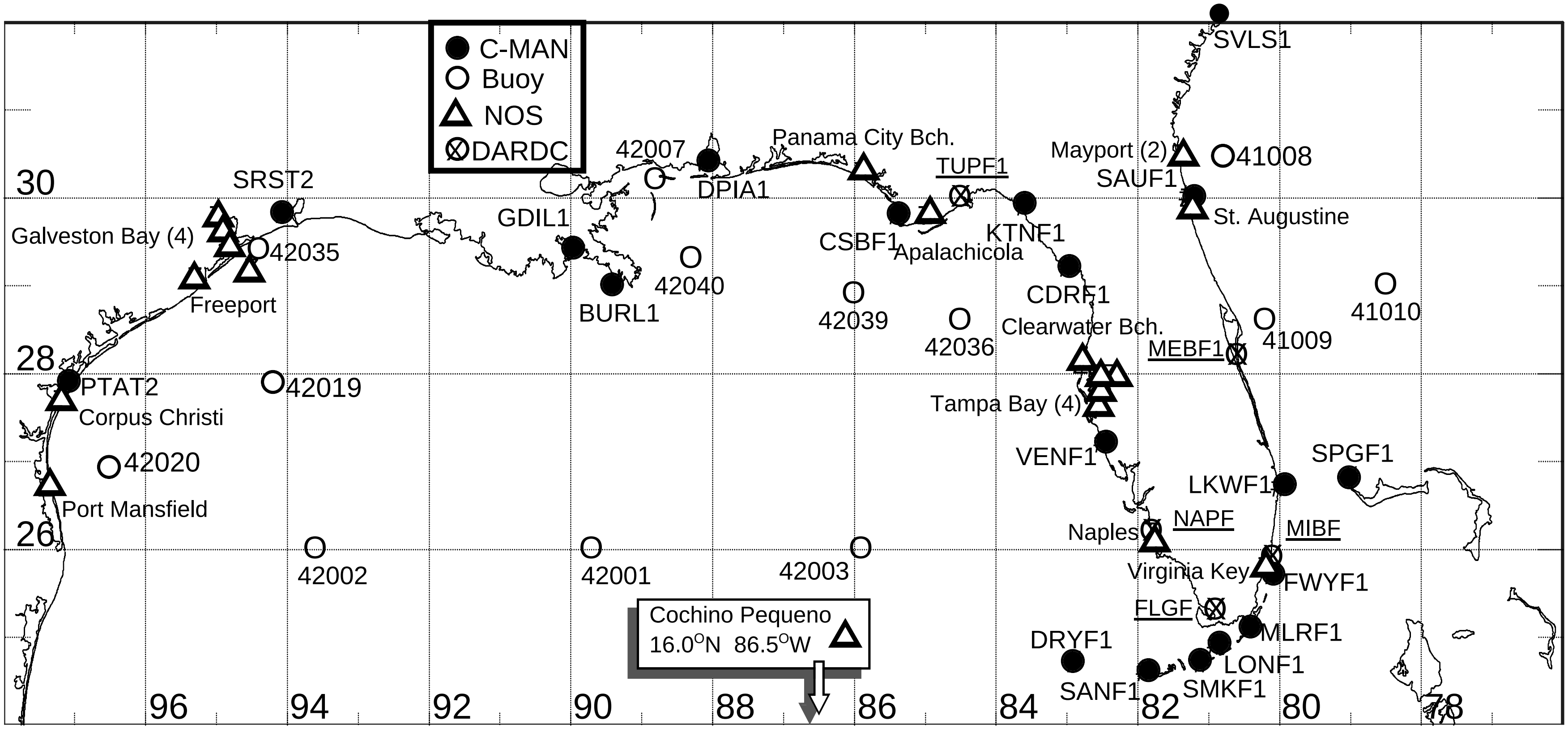


Fig. C-2. Marine buoy, C-MAN, NOS (lower case), and DARDC (underlined) locations in the Gulf of Mexico, Florida, and southern Georgia. See Tables C-3.1 -- C-3.5.

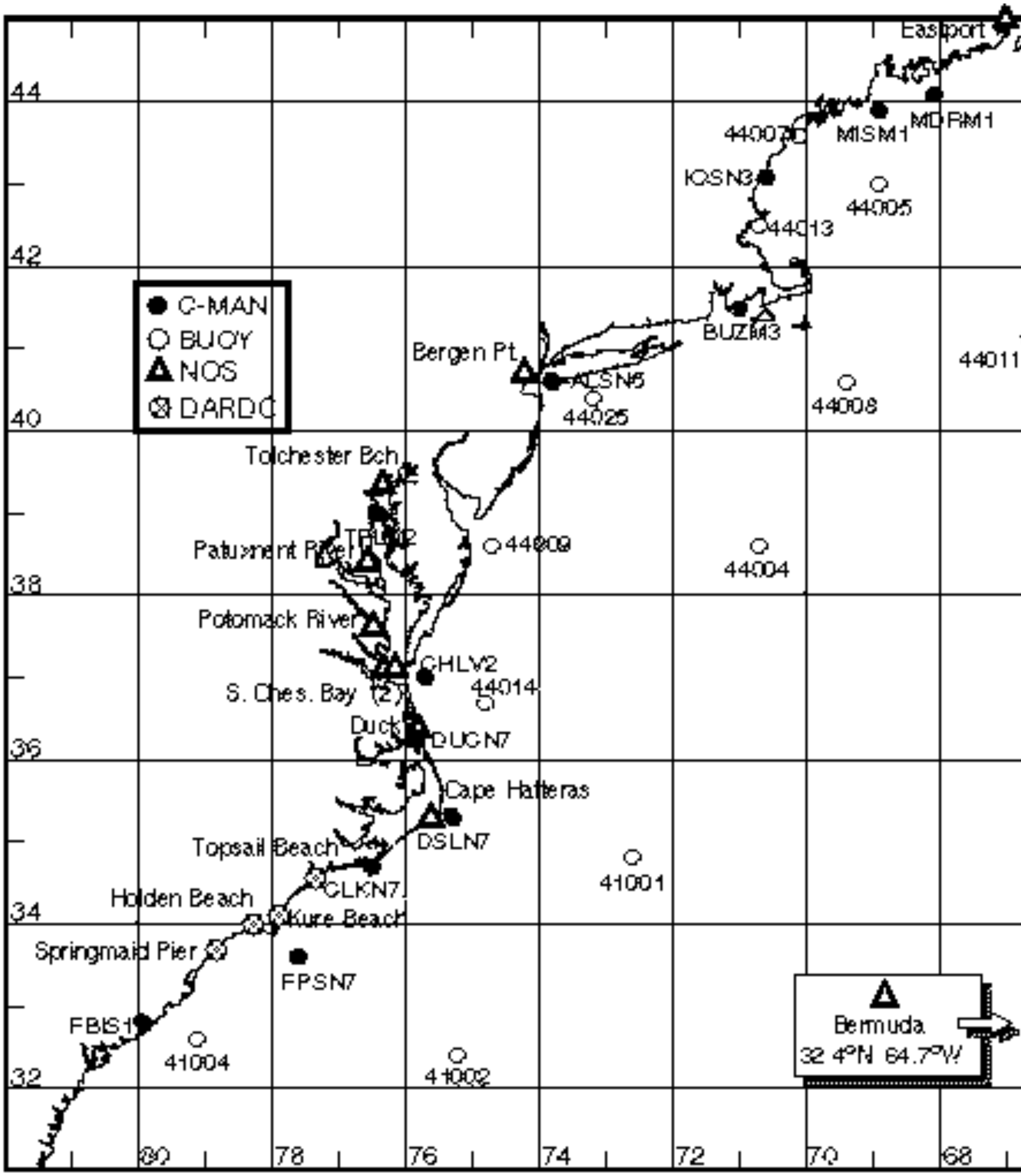


Fig. C-3 Marine buoy, C-MAN, and NOS (lower case) locations for the U.S. east coast.
See Tables C-3.1 -- C-3.5.

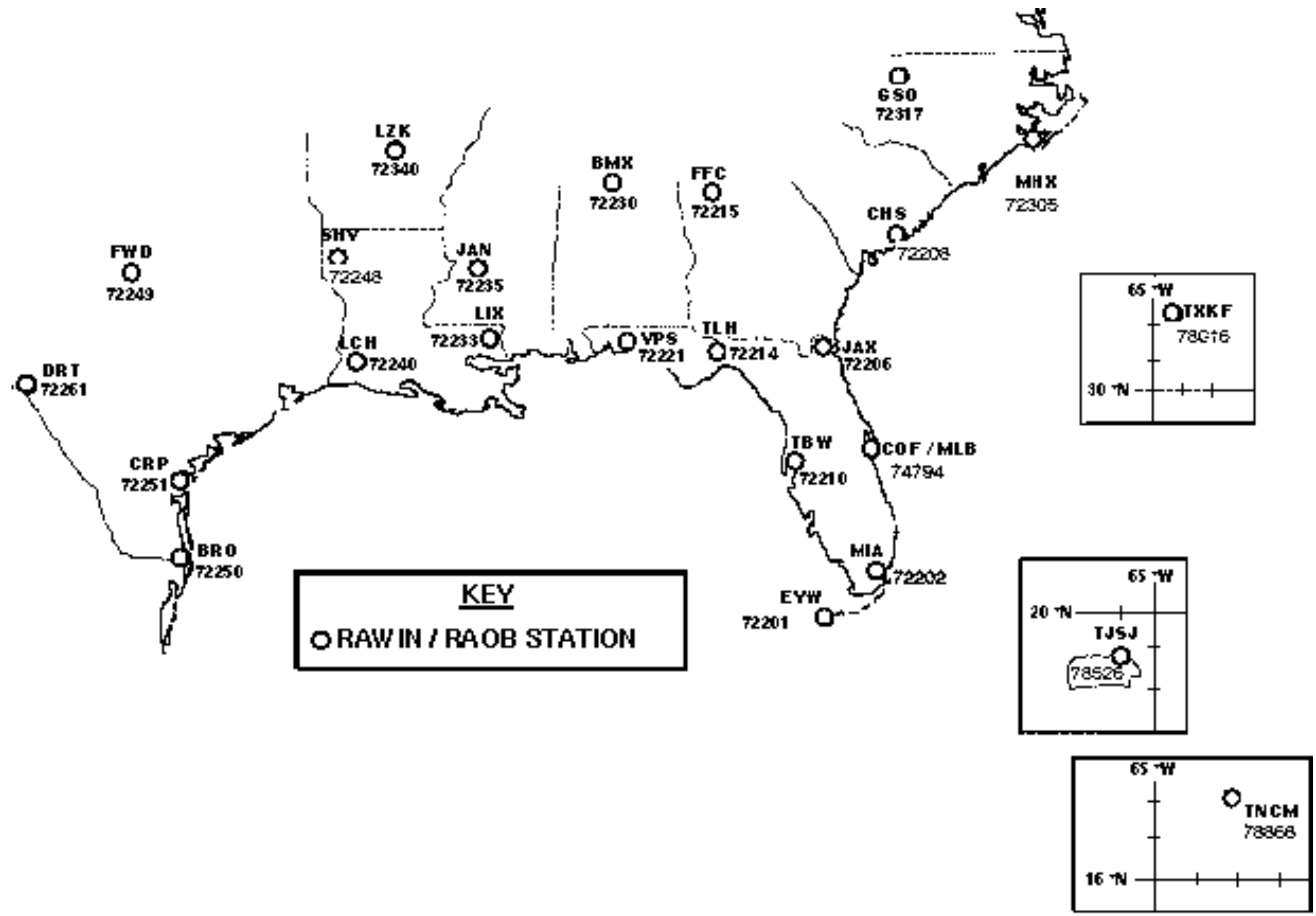


Fig. C-4. Locations of RAWIN/RAOB. See tables C-4.1 -- C-4.5 for complete information.

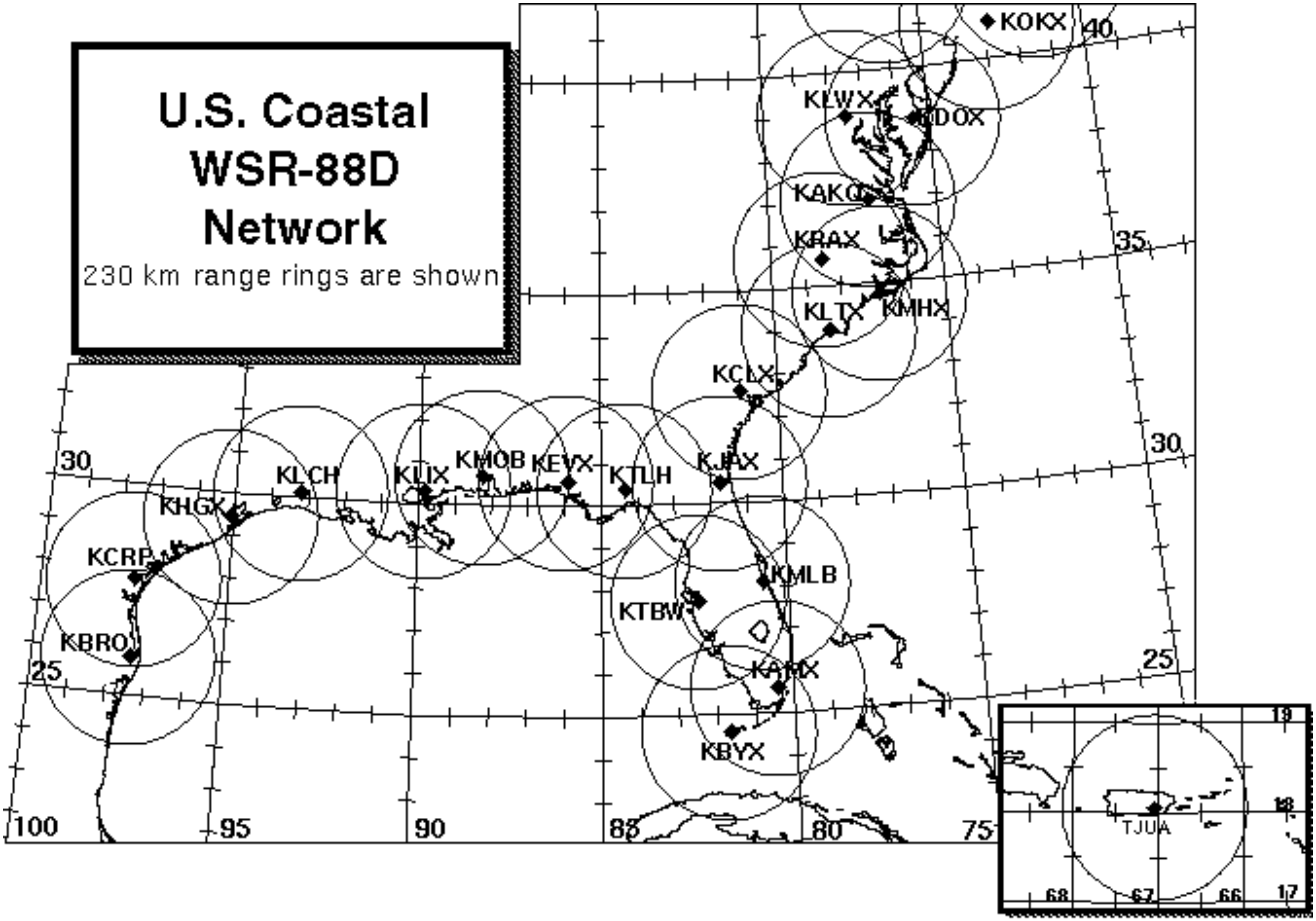


Fig. C-5. Locations of coastal WSR-88D stations. See tables C-4.1 -- C-4.5 for complete information.

APPENDIX D:

PRINCIPAL DUTIES OF THE NOAA SCIENTIFIC PERSONNEL

PRINCIPAL DUTIES OF THE NOAA 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 post flight 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 post flight status report and flight summary of each mission day's operations to the on-board lead project scientist at the post flight 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 post flight checks and calibrations.

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

APPENDIX E:

NOAA RESEARCH OPERATIONAL PROCEDURES AND CHECK LISTS

NOAA RESEARCH OPERATIONAL PROCEDURES AND CHECK LISTS

E.1 Mission Directives: "Conditions-of-Flight" Commands

Mission participants should be aware of the designated "conditions-of-flight." There are five designated basic conditions of readiness encountered during flight. The pilot will set a specific condition and announce it to all personnel over the aircraft's PA (public address) and ICS (interphone communications systems). All personnel are expected to take action in accordance with the instructions for the specific condition announced by the pilot. These conditions and appropriate actions are shown below.

CONDITION 1: TURBULENCE/PENETRATION. All personnel will stow loose equipment and fasten safety belts.

CONDITION 2: HIGH ALTITUDE TRANSIT/FERRY. There are no cabin station manning requirements.

CONDITION 3: NORMAL MISSION OPERATIONS. All scientific and flight crew stations are to be manned with equipment checked and operating as dictated by mission requirements. Personnel are free to leave their ditching stations and smoking is permitted.

CONDITION 4: AIRCRAFT INSPECTION. After take-off, crew members will perform a wings, engines, electronic bays, lower compartments, and aircraft systems check. All other personnel will remain seated with safety belts fastened and headsets on. Smoking is prohibited.

CONDITION 5: TAKE-OFF/LANDING. All personnel will extinguish all smoking materials, stow or secure loose equipment, don headsets, and fasten safety belts/shoulder harnesses.

E.2 Lead Project Scientist

E.2.1 Preflight

_____ 1. Participate in general mission briefing.

_____ 2. Determine specific mission and flight requirements for assigned aircraft.

_____ 3. Determine from CARCAH or field program director whether aircraft has operational fix responsibility and discuss with AOC flight director/meteorologist and CARCAH unless briefed otherwise by field program director.

_____ 4. Contact HRD members of crew to:

a. Assure availability for mission.
b. Arrange ground transportation schedule when deployed.
c. Determine equipment status.

_____ 5. Meet with AOC flight crew at least 90 minutes before takeoff, provide copies of flight requirements, and provide a formal briefing for the flight director, navigator, and pilots.

_____ 6. Report status of aircraft, systems, necessary on-board supplies and crews to appropriate HRD operations center (MGOC in Miami).

E.2.2 In-Flight

_____ 1. Confirm from AOC flight director that satellite data link is operative (information).

_____ 2. Confirm camera mode of operation.

_____ 3. Confirm data recording rate.

_____ 4. Complete Form E-2.

E.2.3 Post flight

_____ 1. Debrief scientific crew.

_____ 2. Report landing time, aircraft, crew, and mission status along with supplies (tapes, *etc.*) remaining aboard the aircraft to MGOC.

_____ 3. Gather completed forms for mission and turn in at the appropriate operations center. [**Note**: all data removed from the aircraft by HRD personnel should be cleared with the AOC flight director.]

_____ 4. Obtain a copy of the 10-s flight listing from the AOC flight director. Turn in with completed forms.

_____ 5. Determine next mission status, if any, and brief crews as necessary.

_____ 6. Notify MGOC as to where you can be contacted and arrange for any further coordination required.

_____ 7. Prepare written mission summary using form E-2 p.3 (due to Field Program Director1 week after the flight).

Form E-2
Page 1 of 5

Lead Project Scientist Check List

Date ___________________ **Aircraft** _____________ **Flight ID** ____________________

A. —Participants:

HRD		AOC	
Function	**Participant**	**Function**	**Participant**
Lead Project Scientist		Flight Director	
Cloud Physics		Pilots	
Radar		Navigator	
Workstation		Systems Engineer	
Photographer/Observer		Data Technician	
Dropwindsonde		Electronics Technician	
AXBT/AXCP/Guest		Other	

Take-Off: ________ Location: _______________ Landing: ________ Location: _________________

Number of Eye Penetrations: ______

B. —Past and Forecast Storm Locations:

Date/Time	Latitude	Longitude	MSLP	Maximum Wind

C. —Mission Briefing:

Form E-2
Page 2 of 5

D. —Equipment Status (Up ↑, Down ↓, Not Available **—**, Not Used **O**)

Equipment	Pre-Flight	In-Flight	Post-Flight	# of DATs or Expendables
Aircraft				
Radar/LF				
Radar/TA (Doppler)				
Cloud Physics				
Data System				
Dropwindsondes				
AXBT/AXCP				
Workstation				
Videography				

REMARKS:

Mission Summary
Storm name
YYMMDDA# Aircraft 4_RF

Scientific Crew (4 RF)

Lead Project Scientist	____________________
Radar Scientist	____________________
Cloud Physics Scientist	____________________
Dropwindsonde Scientist	____________________
Boundary-Layer Scientist	____________________
Workstation Scientist	____________________
Observers	____________________

Mission Briefing: (include sketch of proposed flight track or page #)

Mission Synopsis: (include plot of actual flight track)

Evaluation: (did the experiment meet the proposed objectives?)

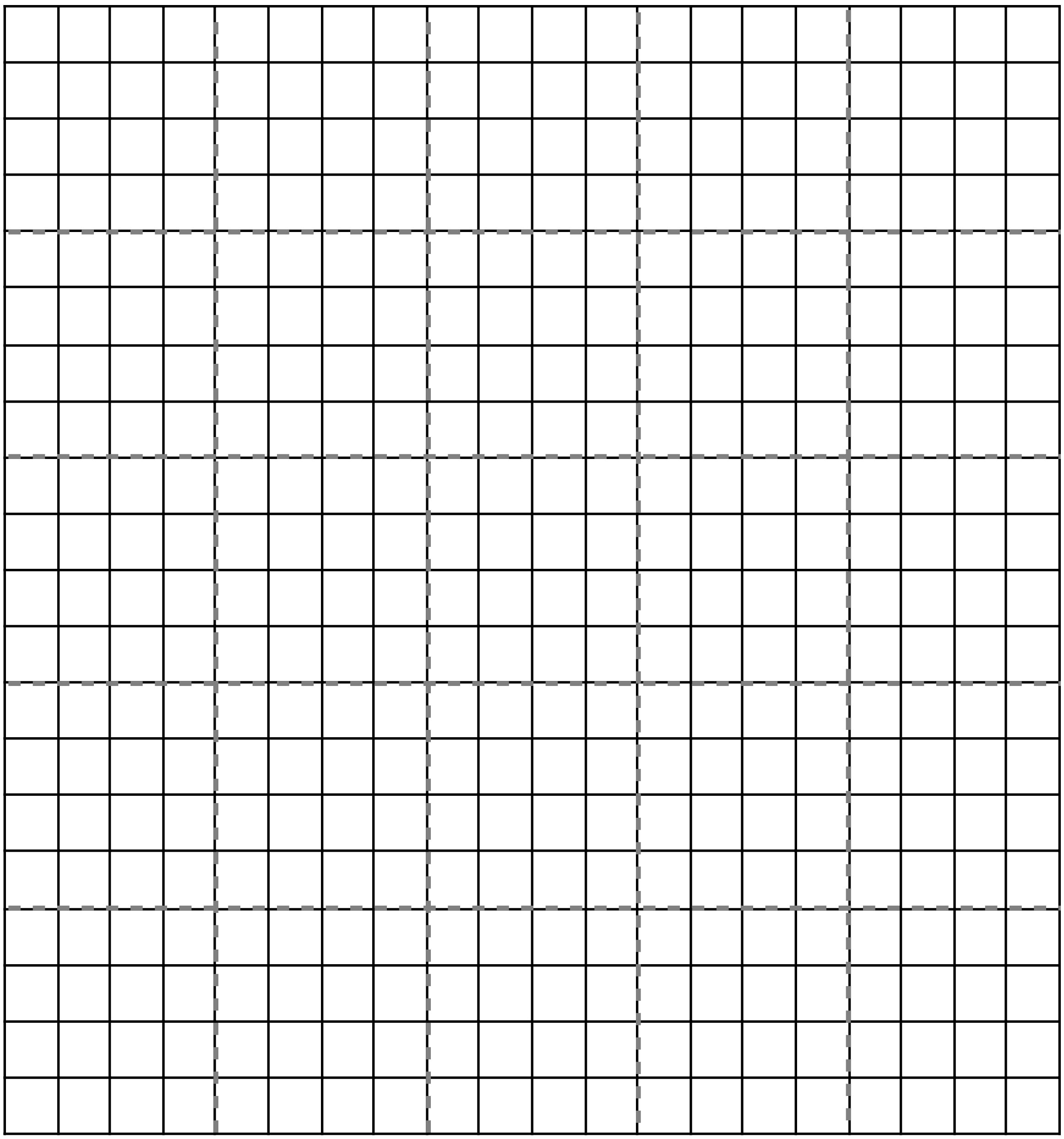
Problems:(list all problems)

Page __of __

Observer's Flight Track Worksheet

Date ________________ Flight ________________ Observer _________________

Latitude (°)



Longitude (°)

Lead Project Scientist Event Log

Date ________________ Flight ________________ LPS _________________

Time	Event	Position	Comments

E.3 Cloud Physics Scientist

The on-board cloud physics scientist (CPS) is responsible for cloud physics data collection on his/her assigned aircraft. Detailed operational procedures are contained in the cloud physics kit supplied for each aircraft. General procedures follow. (Check off and initial.)

E.3.1 Preflight

_____ 1. Determine status of cloud physics instrumentation systems and report to the on-board lead project scientist (LPS).

_____ 2. Confirm mission and pattern selection from the on-board LPS.

_____ 3. Select mode of instrument operation.

_____ 4. Complete appropriate instrumentation preflight check lists as supplied in the cloud physics operator's kit.

E.3.2 In-Flight

_____ 1. Operate instruments as specified in the cloud physics operator's kit and as directed by the on-board LPS.

E.3.3 Post flight

_____ 1. Complete summary check list forms and all other appropriate forms.

_____ 2. Brief the on-board LPS on equipment status and turn in completed check sheets to the LPS.

_____ 3. Take cloud physics data tapes and other data forms and turn these data sets in as follows:

a. Outside of Miami - to the LPS.
b. In Miami - to AOML/HRD. [**Note**: all data removed from the aircraft by HRD personnel should be cleared with the AOC flight director.]

_____ 4. Debrief as necessary at MGOC or the hotel during a deployment.

_____ 5. Determine the status of future missions and notify MGOC as to where you can be contacted.

Form E-3
Page 1 of 3

Cloud Physics Scientist Check List

Date ________________ **Aircraft** _______________ **Flight ID** _____________

A. —Instrument Status and Performance:

System	Pre-Flight	In-Flight	Downtime	# of Tapes
Johnson-Williams				
PMS Probes:				
—2D-P				
—2D-C				
—FSSP				
—Data System				
—Recorder				
FORMVAR				
DRI Charge Probe				
DRI Field Mills				
King Probe				

B. —Remarks:

Form E-3

2-D Knollenberg Data Tape Log

Date ________________ **Flight** _________________ **Operator** ___________________

Tape #	EOF #	Time On	Time Off	Comments

FORMVAR Log

Date ________________ **Flight** _________________ **Operator** __________________

Roll #	Time On	Time Off	Frame Count at Start	Comments

E.4 Boundary-Layer Scientist

The on-board boundary-layer scientist (BLS) is responsible for data collection from AXBTs, AXCPs, AXCTDs, BUOYs, and sea surface temperature radiometers (if these systems are used on the mission). Detailed calibration and instrument operation procedures are contained in the air-sea interaction (ASI) manual supplied to each operator. General supplementary procedures follow. (Check off and initial.)

E.4.1 Preflight

_____ 1. Determine the status of equipment and report results to the on-board lead project scientist (LPS).

_____ 2. Confirm mission and pattern selection from the on-board LPS.

_____ 3. Select the mode of operation for instruments after consultation with the HRD/BLS and the on-board LPS.

_____ 4. Complete appropriate preflight check lists as specified in the ASI manual and as directed from the on-board LPS.

E.4.2 In-Flight

_____ 1. Operate the instruments as specified in the ASI manual and as directed by the on-board LPS.

E.4.3 Post flight

_____ 1. Complete summary check list forms and all other appropriate check list forms.

_____ 2. Brief the on-board LPS on equipment status and turn in completed check lists to the LPS.

_____ 3. Debrief as necessary at MGOC or the hotel during a deployment.

_____ 4. Determine the status of future missions and notify MGOC as to where you can be contacted.

Form E-4
Page 1 of 3

AXBT/AXCP Check Sheet Summary

Flight ___________ **Aircraft** ______ **Operator** ___________

		Number
(1)	Probes dropped	_______
(2)	Failures..	_______
(3)	Failures with no signal	_______
(4)	Failures with sea surface temperature, but terminated above thermocline....................	_______
(5)	Probes that terminated above 250 m, but below thermocline	_______
(6)	Probes used by channel number CH12	_______
	.... CH14	_______
	.... CH16	_______
	.... CH__	_______

NOTES:

Form E-4
Page 2 of 3

AXBT and AXCP Check Sheet

Flight Number ______________________ AXBT/AXCP Contract Number _________________

Take-Off Time ______________________ Landing Time ______________________________

Storm ____________________________ Storm Direction/Speed ______________________

AXCP/ AXBT #/Type	Channel Number	Lot Number	Drop Time (HHMMSS)	Lat. Deg. Min.		Long. Deg. Min.		Surface Temp. AXBT IRT		MLD (m)	Comments

Form E-4
Page 3 of 3

AXCP Log

Flight Number ______________________ AXBT/AXCP Contract Number ________________

Take-Off Time ______________________ Landing Time ____________________________

Storm ____________________________ Storm Direction/Speed ______________________

Leg Number	Out/In	RA (m)	PMIN (mb)	VMAX (m/s)	RMAX (km)	Time PMIN	Time VMAX	Time End Pass

Leg/ Drop #	Tube #	Channel #	Probe Type		Ground Speed	Drop Time (HHMMSS)	Latitude (deg min)	Longitude (deg min)	Status		Comments
			Slow	Reg					Good	Bad	

E.5 Radar Scientist

The on-board Doppler radar scientist (DRS) is responsible for data collection from all radar systems on his/her assigned aircraft. Detailed operational procedures and check lists are contained in the operator's manual supplied to each operator. General supplementary procedures follow. (Check off and initial.)

E.5.1 Preflight

_____ 1. Determine the status of equipment and report results to the on-board lead project scientist (LPS).

_____ 2. Confirm mission and pattern selection from the on-board LPS.

_____ 3. Select the operational mode for radar system(s) after consultation with the on-board LPS.

_____ 4. Complete the appropriate preflight calibrations and check lists as specified in the radar operator's manual.

E.5.2 In-Flight

_____ 1. Operate the system(s) as specified in the operator's manual and as directed by the on-board LPS or as required for aircraft safety as determined by the AOC flight director or aircraft commander.

_____ 2. Maintain a written commentary in the radar logbook of tape and event times, such as the start and end times of F/AST legs. Also document any equipment problems or changes in R/T, INE, or signal status.

E.5.3 Post flight

_____ 1. Complete the summary check lists and all other appropriate check lists and forms.

_____ 2. Brief the on-board LPS on equipment status and turn in completed forms to the LPS.

_____ 3. Hand-carry all radar tapes and arrange delivery as follows:

a. Outside of Miami - to the LPS.
b. In Miami - to MGOC or to AOML/HRD. [**Note**: all data removed from the aircraft by HRD personnel should be cleared with the AOC flight director.]

_____ 4. Debrief at MGOC or the hotel during a deployment.

_____ 5. Determine the status of future missions and notify MGOC as to where you can be contacted.

HRD Radar Scientist Check List

Flight ID: ______________________________

Aircraft Number: ______________________________

Doppler Radar Operators: ______________________________

Radar Technician: ______________________________

Number of digital magnetic tapes on board: ______________

Component Systems Status:

MARS ______________	Computer ______________
DAT1______________	DAT2 ______________
LF ______________	R/T Serial # ______________
TA ______________	R/T Serial # ______________

Time correction between radar time and digital time: ____________

Radar Post flight Summary

Number of digital tapes used: DAT1 ____________

DAT2 ____________

Significant down time:

DAT1 ____________	Radar LF ____________
DAT2 ____________	Radar TA ____________

Other Problems:

HRD Radar Tape Log

Flight ___________ **Aircraft** ______ **Operator** ___________ Sheet ____ of ____

LF RPM _______________ TA RPM ______________

(Include start and end times of DATs, as well as times of F/AST legs and any changes of radar equipment status)

Tape #	F/AST On?	Event Time (HHMMSS)	Event

HRD Radar Down-Time Log

Flight ___________ **Aircraft** ______ **Operator** ___________ Sheet ____ of ____

Item	Time Down (HHMMSS)	Time Up (HHMMSS)	Problem

Item List: DAT1, DAT2, COMP, MARS, LF, TA.

Include serial numbers of any new R/Ts.

E.6 Dropwindsonde Scientist

The on-board lead project scientist (LPS) on each aircraft is responsible for determining the distribution patterns for dropwindsonde releases. Predetermined desired data collection patterns are illustrated on the flight patterns. However, these patterns often are required to be altered because of clearance problems, etc. Operational procedures are contained in the operator's manual. The following list contains more general supplementary procedures to be followed. (Check off and initial.)

E.6.1 Preflight

_____ 1. Determine the status of equipment and report results to the on-board LPS.

_____ 2. Confirm the mission and pattern selection from the LPS and assure that the proper number and distribution (frequency) of dropwindsonde s are on board the aircraft.

_____ 3. Complete the appropriate preflight calibrations and check lists.

E.6.2 In-Flight

_____ 1. Operate the system as specified in the operator's manual.

_____ 2. Obtain drop release approval (for each drop) from the AOC flight director or navigator for each specific time and location of drop.

_____ 3. Report to the LPS as soon as it is determined that the dropwindsonde is (or is not) transmitting a good signal.

_____ 4. Report completion of each drop and readiness for the next drop.

_____ 5. Complete Form E-6.

E.6.3 Post flight

_____ 1. Complete the summary form for dropwindsondes.

_____ 2. Brief the on-board LPS on equipment status and turn in reports and completed forms to the LPS.

_____ 3. Hand-carry all dropwindsonde data tapes and printouts and inform the AOC flight director that you are arranging delivery as follows:

a. Outside of Miami - to the LPS.
b. In Miami - to AOML/HRD (temporarily), either directly or via MGOC, for conversion to 9-track magnetic tapes.

_____ 4. Debrief at the MGOC or the hotel during a deployment.

_____ 5. Determine the status of future missions and notify MGOC as to where you can be contacted.

Form E-6

Page ___ of ___

HRD Omega Dropwindsonde Scientist Log

Flight ______________________________

Storm ______________________________

ODW Scientists ___________________________

____

____

AOC Operator ___________________________

Drop #	Sonde ID #	Time (HHMMSS)	Latitude (°)	Longitude (°)	Wind (m/s) (WD/WS)	Height (GA)	Temp. (TA)	Dew Point (TD)	Pressure (PS)	Remarks

APPENDIX F:

GROUND OPERATION

GROUND OPERATION

In support of each field operation, a ground coordination team will serve on the staff of the HRD director. The ground coordination team will consist of the Miami Ground Operations Center (MGOC).

(1) Staff:

H. Friedman (senior team leader)
R. Jones (team leader)
J. Berkeley (meteorological technical support)

(2) Operational Scheduling:

During research missions the MGOC staff will form three teams as follows: one team leader and, when necessary and available, one meteorological technician support person. Each team will work an (approximately) 8-h shift; shifts will continue for the duration of operations or until MGOC personnel are released by the field program director or his designee.

(3) General Duties:

During operations, the MGOC acts as the liaison between HRD and other organizations as required by the field program director, the HRD director, or their designated representatives. Duties of the MGOC include the following:

a. Collect, plot, and file data from NHC.

b. Update messages on the auto-phone tape at MGOC (NHC).

c. Coordinate the acquisition of satellite photos for operational and research purposes.

d. Make motel/hotel reservations at alternate recovery sites as requested by field operations personnel.

e. Handle press affairs in Miami as follows:

- Refer press inquiries to D. Konop, OAR/PA.
- Refer forecast inquiries to NHC.

f. Communicate with AOC ground coordinator and NASA CAMEX-3 Mission Planning Team, as required.

g. Make requests for special radar and/or rawinsonde (upper air) observations, subject to approval by the HRD director.

h. Maintain a crew status report of HRD participants for current and proposed missions. When missions are being conducted away from Miami, crew status information will be reported to MGOC by the field program director or his designee.

(4) Phone numbers:

NHC Public Affairs/F. Lepore	(305)229-4404
AOC	(813)828-3310
AOC (FAX)	(813)828-3266
AOC (auto line)	(813)828-3310 —— (ext. 3082)
HRD (auto line at MGOC/TPC/NHC)	(305)221-3679
HRD (voice line at MGOC/TPC/NHC)	(305)221-4381
HRD FAX number	(305)361-4402
AOC (communications)	(813)828-3310 —— (ext. 3105)
AOC's long distance auto announce phone number	(800)729-6622
NASA NUMBERS...	—— TBA
OAR/PA (D. Konop)	(301)713-2483
TPC/NHC (WFO)	(305) 229-4528
Miami Ground Operations Center (MGOC) at NHC	(305)229-4407
Miami Ground Operations Center (MGOC) at HRD/AOML	(305)361-4400
Zephyr/WIS Center at HRD/AOML	(305)361-4368
TRDIS Operations at NHC	(305)229-4429
Storm Surge Group at NHC	(305)229-4456
WWV (for time check)	(303)499-7111
Telepager (beeper) numbers for MGOC team leaders, H. Willoughby and F. Marks (HRD), and J. McFadden (AOC)	—— TBA

(5) Supplies:

a. Up-to-date phone list

b. Current copies of the following:

- HRD Hurricane Field Program Plan
- AOC Hurricane Operations Plan (if available)
- MGOC Manual (black, loose-leaf book)

(6) Information Pool:

Interface with NHC and others as required, and at appropriate times, obtain:

a. Satellite fixes at forecast times and 3-hourly intermediate fixes.

b. NHC official releases:

- Storm position and current strength and movement (including maximum wind and minimum—pressure).
- Forecast storm position and strength (wind and pressure) for 12, 24, 48, and 72 h.
- 0400, 1000, 1600, 2200 UTC and all intermediate advisories (based on synoptic 0000, 0600, 1200, and 1800 UTC).
- Public advisories.

c. NHC supplied additional data:

- 3-hourly storm positions.
- Aircraft reconnaissance reports (request extra copy from NHC Communications Unit).
- HURCAS computer product (request extra copy from NHC/Tropical Satellite and Analysis Center: 2130, 0330, 0930, 1530 EDT availability).

APPENDIX G:

NOAA EXPENDABLES AND SUPPLIES

NOAA EXPENDABLES AND SUPPLIES

Table G-1. DAT Tape, Dropsonde, AXBT/BUOY Requirements Per Experiment[1]

Experiment	Cloud Physics	DAT Tapes Slow/Fast/Radar	DW[2] OP[2] BO[2]
Hurricane Synoptic-Flow Experiment (single-option, dual-aircraft mission)	02	01 / 00 / 04	65 00 00
Extended Cyclone Dynamics Experiment (single-option, two-aircraft mission)	01	01 / 00 / 04	30 00 00
Vortex Motion and Evolution Experiment (single-option, dual-aircraft mission)			
High-level aircraft.	03	01/ 00 / 04	44 00 00
Low-level aircraft.	03	01 / 00 / 04	1510 00
Tropical Cyclogenesis Experiment (single-option, dual-aircraft mission)			
High-level aircraft.	03	01 / 00 / 04	30 00 00
Low-level aircraft.	03	01 / 02 / 04	1010 00
Tropical Cyclone Wind fields at Landfall (dual-option, single-aircraft mission)	01	01 / 02 / 04	25 00 00
Tropical Cyclone Air-sea Interaction Experiment (multi-option, single-aircraft mission)			
Option 1: Pre-landfall Option (dual-aircraft mission)	01	01 / 02 / 04	10 41 03
Option 2: Near-landfall Option (dual-aircraft mission)	01	01 / 02 / 04	10 31 03
Option 3: Post-landfall Option (dual-aircraft mission)	01	01 / 02 / 04	40 56 00

Rainband Structure Experiment (multi-option, multi-aircraft mission)			
Option 1: Rainband Option (dual-aircraft mission)	01	01 / 02 / 04	25 00 00
Option 2: Concentric Eyewall Option (dual-aircraft mission)	01	01 / 02 / 04	25 00 00
Electrification of Tropical Cyclone Convection Experiment (single-option, single-aircraft mission)	03	01 / 02 / 04	20 00 00
Eyewall Vertical Motion Structure Experiment (single-option dual-aircraft mission)			
High-level aircraft	03	01 / 02 / 05	20 00 00
Low-level aircraft.	03	01 / 02 / 05	10 00 00
Clouds and Climate Study (single-option dual-aircraft mission)	03	01 / 02 / 05	15 00 00

1 A mission is defined as one launch and recovery for research purposes. Entries shown for dual-aircraft (nonsequential mode) missions are for the total number of DAT tapes, Dropwindsondes, AXBT's, AXCPs, AXCTDs, and BUOY's required for each experimental day's operation. Entries shown for two-aircraft, sequential mode operation missions are the requirements for each aircraft participating on each experimental day's operation.

2 DW = GPS dropwindsonde; OP = AXBT, AXCP, AXCTD; BO = BUOY.

APPENDIX H:

SYSTEMS OF MEASURE AND UNIT CONVERSION FACTORS

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
ARMAR	DC-8 Doppler radar
ASDL	aircraft-satellite data link
AXBT	airborne expendable bathythermograph
AXCP	airborne expendable current probe
AXCTD	airborne expendable conductivity, temperature, and depth probe
BLS	boundary layer scientist
CAMEX-3	NASA Third Convection and Moisture Experiment
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
EDOP	ER-2 Doppler radar
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
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

LASE	NASA DC-8 Differential Absorption Lidar
LF	lower fuselage (radar)
LIP	DC-8 and ER-2 lightning instrument package
LPS	Lead Project Scientist
MCS	mesoscale convective systems
MGOC	Miami Ground Operations Center
MPO	Meteorology and Physical Oceanography
NASA	National Aeronautics and Space Administration
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
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
PDD	pseudo-dual Doppler
PMS	Particle Measuring Systems
POD	Plan of the Day
PPI	plan position indicator
PV	potential vorticity
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)
SRA	Scanning Radar Altimeter
SST	sea-surface temperature
TA	tail (radar)
TAS	true airspeed
TC	tropical cyclone
TEFLUN	NASA Texas-Florida Underflights Experiment
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)
VSDR	Vertically Scanning Doppler Radar
VTD	velocity-track display
XCDX	Extended Cyclone Dynamics Experiment

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