EXPERIMENT AND MODULE DESCRIPTIONS

1. P-3 Three-Dimensional Doppler Winds Experiment

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Primary IFEX Goal: 1 - Collect observations that span the TC life cycle in a variety of environments for model initialization and evaluation

Program significance: This experiment is a response to the requirement listed as Core Doppler Radar in Section 5.4.2.9 of the National Hurricane Operations Plan. The goal of that particular mission is to gather airborne-Doppler wind measurements that permit an accurate initialization of HWRF, and also provide three-dimensional wind analyses for forecasters.

There are five main goals: 1) to provide a comprehensive data set for the initialization (including data assimilation) and validation of numerical hurricane simulations (in particular HWRF), 2) to improve understanding of the factors leading to TC intensity and structure changes by examining as much of the life cycle as possible, 3) to improve and evaluate technologies for observing TCs, 4) to develop rapid real-time communication of these observations to NCEP, and 5) to contribute to a growing tropical-cyclone database that permits the analysis of statistics of quantities within tropical cyclones of varying intensity.

The ultimate requirement for EMC is to obtain the three-dimensional wind field of Atlantic TCs from airborne Doppler data every 6 h to provide an initialization of HWRF through assimilation every 6 h. The maximum possible rotation of missions is two per day or every 12 h. A "poor man's" version of the 6 h data collection is to collect data in the last half of one 6-h observing period, and in the first half of the next 6-h observing period. In hurricanes, coordination will be required between HRD, NCEP, and NESDIS, to effectively collect observations for both the Three- Dimensional Doppler Winds Experiment and the Ocean Winds and Rain Experiment, a NESDIS program designed to improve understanding of satellite microwave surface scatterometery in high-wind conditions over the ocean by collecting surface scatterometery data and Doppler data in the boundary layer of hurricanes.

The highest vertical resolution is needed in the boundary and outflow layers. This is assumed to be where the most vertical resolution is needed in observations to verify the initialization and model. For this reason it is desirable that if sufficient dropwindsondes are available, they should be deployed in the radial penetrations in the Three-Dimensional Doppler Winds experiment to verify that the boundary-layer and surface wind forecasts produced by HWRF resemble those in observations. These observations will also supplement airborne Doppler observations, particularly in sectors of the storm without sufficient precipitation for radar reflectivity. If sufficient dropwindsondes are not available, a combination of SFMR, Advanced Wind and Rain Airborne Profiler (AWRAP), and airborne Doppler data will be used for verification.

Links to IFEX: The P-3 Tail Doppler Radar experiment supports the following NOAA IFEX goals:

Goal 1: Collect observations that span the TC lifecycle in a variety of environments
Goal 2: Develop and refine measurement technologies that provide improved real-time monitoring of TC intensity, structure, and environment
Goal 3: Improve understanding of the physical processes important in intensity change for a TC at all stages of its lifecycle

Mission Descriptions: (The NESDIS Ocean Winds and Rain Experiment will be executed by NESDIS. Specific details regarding these NESDIS missions are not included here)

Three-Dimensional Doppler Winds: Several different options are possible: i) the lawnmower pattern (Fig. 1-1); ii) the box-spiral pattern (Figs. 1-2 and 1-3); iii) the rotating figure-4 pattern (Fig. 1-4); iv) the butterfly pattern that consists of 3 penetrations across the storm center at 60-degree angles with respect to each other (Fig. 1-5); and v) the single figure-4 (Fig. 1-6). These patterns provide the maximum flexibility in planning, in which the need for dense Doppler-radar coverage must be balanced against the need to sample the entire vortex.

Single-aircraft option only: Temporal resolution (here defined as data collected as close as possible to a 6-h interval) is important, for both initialization and verification of HWRF. This has been verified in communication with EMC. To obtain the maximum temporal resolution feasible, this mission is expected to be a single-P-3 mission, to allow another crew to operate 12 h later, and to continue in a 12-h cycle of single sorties. The type of flight pattern will be determined from the organization, strength and radial extent of the circulation. Take-off times will be coordinated to provide quality-controlled Doppler radar observations to NCEP Central Operations (NCO) in every 6-h observing period, by observing the end of one period, and the beginning of the next. This will result generally in a takeoff time at or shortly before 0, 6, 12, or 18 UTC.

Lawnmower pattern: This pattern will be chosen for systems with small, generally asymmetric, weak, newly developed circulations, namely tropical depressions and weak tropical storms. If the system is small enough, lawnmower pattern A (Fig. 1-1) will be chosen, to permit complete coverage of all reflectors within the developing circulation. Otherwise pattern B will be flown. Pattern B permits a larger area to be sampled, at the expense of some gaps in the Doppler coverage. A specific flight level is not required for this mission. It is likely that the Air Force will be flying at an investigation level at this time, and the Three-Dimensional Doppler Winds Experiment can be flown anywhere from 5,000 ft to 12,000 ft. If detailed thermodynamic data from dropwindsondes is desirable, or the distribution of Doppler winds is highly asymmetric, then the preferred level would be 12,000 ft to allow the deepest observation of the thermodynamic and wind structure from the dropwindsondes, while reducing the likelihood of lightning strikes and graupel damage by staying below the melting level. Any orientation of the long and short flight legs may be flown, to permit the location of the initial and final points to be closest to the base(s) of operations.

Box-spiral pattern: As the weak, developing, poorly organized circulations become larger, it will be necessary to spread out the pattern to cover a larger area at the expense of complete Doppler coverage. Pattern A, as shown in Fig. 1-2, is designed to cover a box 280 nm x 280 nm with radial gaps in the coverage. As long as the circulation is still weak, but covers a larger area, this pattern will be considered; however, lack of symmetric coverage at all radii renders this a less viable option as the system organizes. Pattern B has denser coverage within the outside box, and it will be considered in smaller systems. Any orientation of the flight legs may be flown, to permit the location of the initial and final points to be closest to the base(s) of operations.

Rotating figure-4 pattern: As the system intensity and/or organization increases, and a circulation center becomes clearly defined, a rotating figure-4 pattern may be preferred (Fig. 1-4). The advantage of this pattern over the larger versions of the lawnmower pattern is symmetric wind coverage, and the advantage over the box-spiral pattern is good definition of the wind field at all radii within the pattern. This pattern is obviously preferable to the lawnmower pattern in the event there is any operational fix responsibility for the aircraft. Any orientation of the flight legs may be flown, to permit the location of the initial and final points to be closest to the base(s) of operations. See discussion of "lawnmower pattern" regarding flight altitude and use of dropwindsondes.

Butterfly pattern: This pattern (Fig. 1-5) should be flown in larger, well-organized TCs, generally in hurricanes. As the hurricane circulation becomes larger, it will be necessary to get the full radial coverage at the expense of full azimuthal coverage. As an example, a butterfly pattern out to 100 nm could be flown in 3.3 h, compared to a similar lawnmower coverage that would take 4.8 h. This pattern is obviously preferable to the lawnmower pattern in the event there is any operational fix responsibility for the aircraft. Any orientation of the flight legs may be flown, to permit the location of the initial and final points to be closest to the base(s) of operations. See discussion of “lawnmower pattern” regarding flight altitude and use of dropwindsondes.

Single figure-4 pattern: This pattern (Fig. 1-6) will be flown in very large circulations, or when little time is available in storm, such as during ferries from one base of operations to another. It still provides wavenumber 0 and 1 coverage with airborne Doppler data, which should be sufficient in strong, organized systems. Radial coverage out to 240 and 300 nm (4 and 5 degrees) is possible in 5.4 and 6.8 h in pattern. Any orientation of the flight legs may be flown, to permit the location of the initial and final points to be closest to the base(s) of operations. See discussion of “lawnmower pattern” regarding flight altitude and use of dropwindsondes.

Three-Dimensional Doppler Winds Experiment Flight Planning Approach: NOAA will conduct a set of flights during several consecutive days, encompassing as much of a particular storm life cycle as possible. This would entail using the two available P-3s on back-to-back flights on a 12-h schedule when the system is at depression, tropical storm, or hurricane strength.

At times when more than one system could be flown, one may take precedence over others depending on factors such as storm strength and location, operational tasking, and aircraft availability. All other things being equal, the target will be an organizing tropical depression or weak tropical storm, to increase the observations available in these systems. One scenario could likely occur that illustrates how the mission planning is determined: an incipient TC, at depression or weak tropical storm stage is within range of an operational base and is expected to develop and remain within range of operational bases for a period of several days. Here, the highest priority would be to start the set of Three-Dimensional Doppler Winds flights, with single-P-3 missions, while the TC is below hurricane strength (preferably starting at depression stage), with continued single-P-3 missions at 12-h intervals until the system is out of range or makes landfall. During the tropical depression or tropical-storm portion of the vortex lifetime, higher azimuthal resolution of the wind field is preferred over radial extent of observations, while in the hurricane portion, the flight plan would be designed to get wavenumber 0 and 1 coverage of the hurricane out to the largest radius possible, rather than the highest temporal resolution of the eyewall. In all cases adequate spatial coverage is preferred over increased temporal resolution during one sortie.

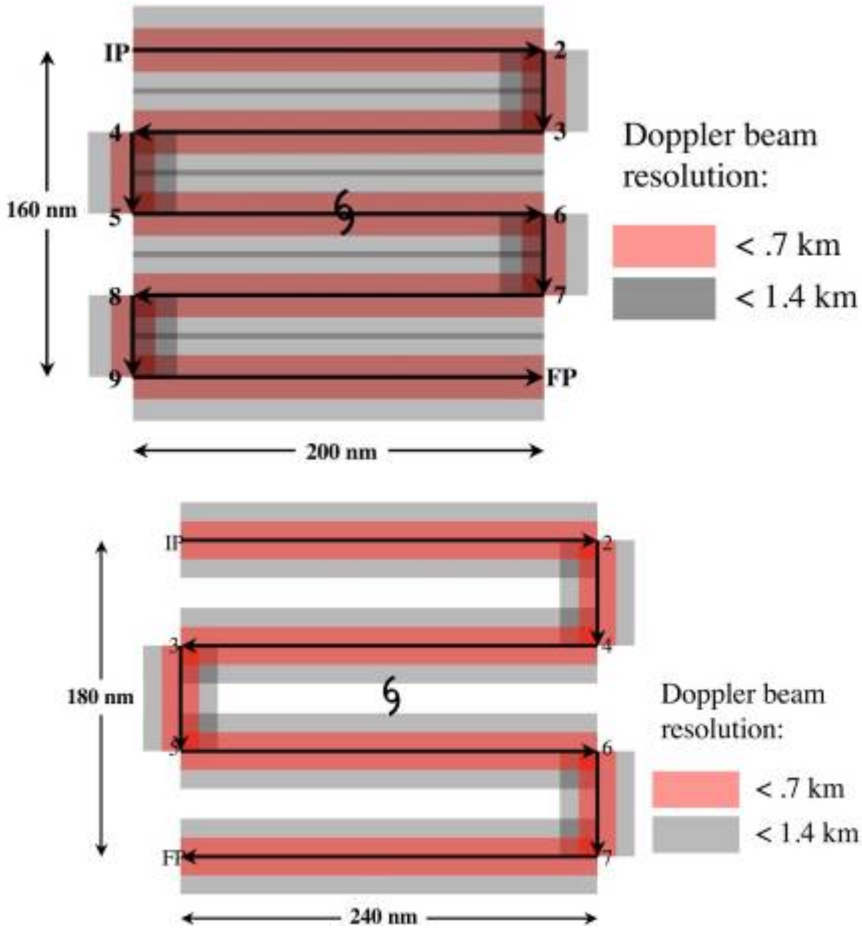


Figure 1-1: Display of Doppler coverage for A (upper panel) and B (lower panel) lawnmower patterns. Pink region shows areas where vertical beam resolution is better than 0.7 km and gray regions delineate areas where vertical beam resolution is better than 1.4 km. Maximum extent of gray area is approximately 40 km from flight track, generally the maximum usable extent of reliable airborne Doppler radar coverage. Total flight distance is 1160 nm for A and 1140 nm for B, and flight times are 4.8 and 4.75 hours, respectively.

Note 1. This is to be flown where even coverage is required, particularly in tropical depressions and tropical storms. Aircraft flies IP-2-3-4-5-6-7-FP. No attempt should be made to fix a center of circulation unless it is an operational request.
Note 2. Doppler radars should be operated in single-PRF mode, at a PRF of 2100. Radar scientist should verify this mode of operation with AOC engineers. If there is no assigned radar scientist, LPS should verify. *This is crucial for the testing and implementation of real-time quality control.*
Note 3. Assure that transmitter is switching between fore and aft antennas, by examining the real time display.
Note 4. IP can be at any desired heading relative to storm center
Note 5. To maximize dropwindsonde coverage aircraft should operate at highest altitudes that still minimize icing
Note 6. If dropwindsondes are not deployed, aircraft can operate at any level below the melting level, with 10,000 ft preferred. Aircraft might also fly lower, if circulation not evident at 10,000 ft.
Note 7. Dropwindsondes are not a required part of this flight plan and are optional.

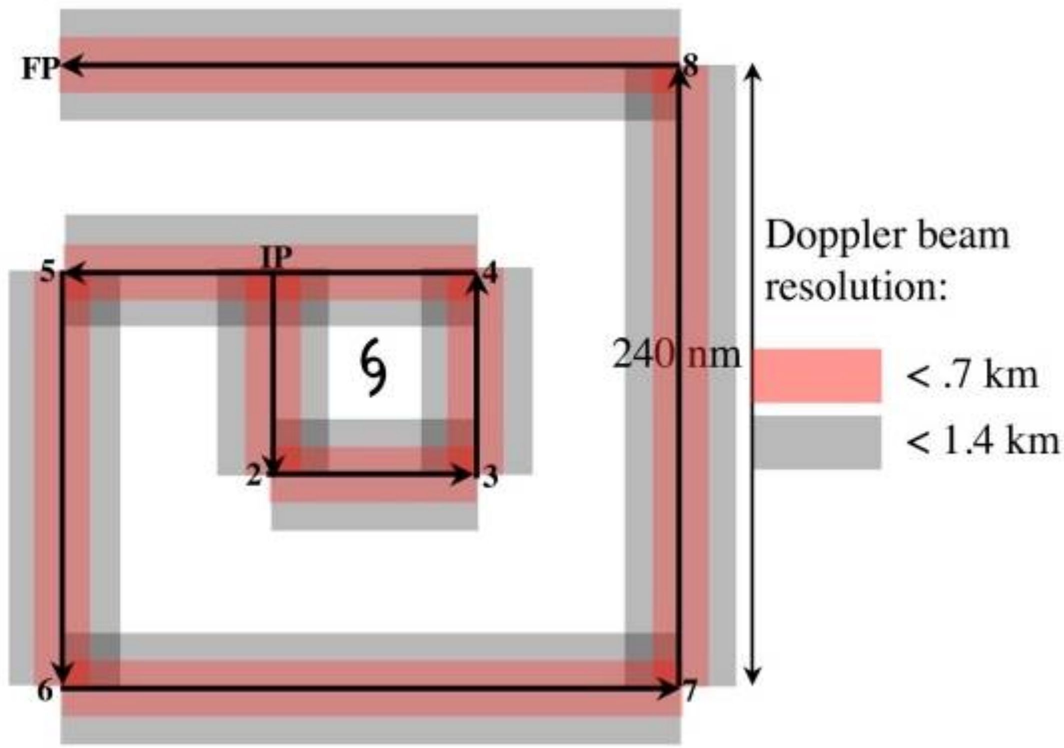


Figure 1-2: Doppler radar coverage for box-spiral pattern A. Pink region shows areas where vertical beam resolution is better than 0.7 km and gray regions delineate areas where vertical beam resolution is better than
1.4 km. Maximum extent of gray area is approximately 40 km from flight track, approximately the maximum usable extent of reliable airborne Doppler radar coverage. Flight distance in pattern above is 1280 nm, and flight time is 5.33 hours.

Note 1. This is to be flown where even coverage is required, particularly in tropical depressions and tropical storms. Aircraft flies IP-2-3-4-5-6-7-8-FP. No attempt should be made to fix a center of circulation unless it is an operational request.
Note 2. Doppler radars should be operated in single-PRF mode, at a PRF of 2100. Radar scientist should verify this mode of operation with AOC engineers. If there is no assigned radar scientist, LPS should verify. *This is crucial for the testing and implementation of real-time quality control.*
Note 3. Assure that transmitter is switching between fore and aft antennas, by examining the real time display.
Note 4. IP can be at any desired heading relative to storm center
Note 5. To maximize dropwindsonde coverage aircraft should operate at highest altitudes that still minimize icing
Note 6. If dropwindsondes are not deployed, aircraft can operate at any level below the melting level, with 10,000 ft preferred. Aircraft might also fly lower, if circulation not evident at 10,000 ft.
Note 7. Dropwindsondes are not a required part of this flight plan and are optional.

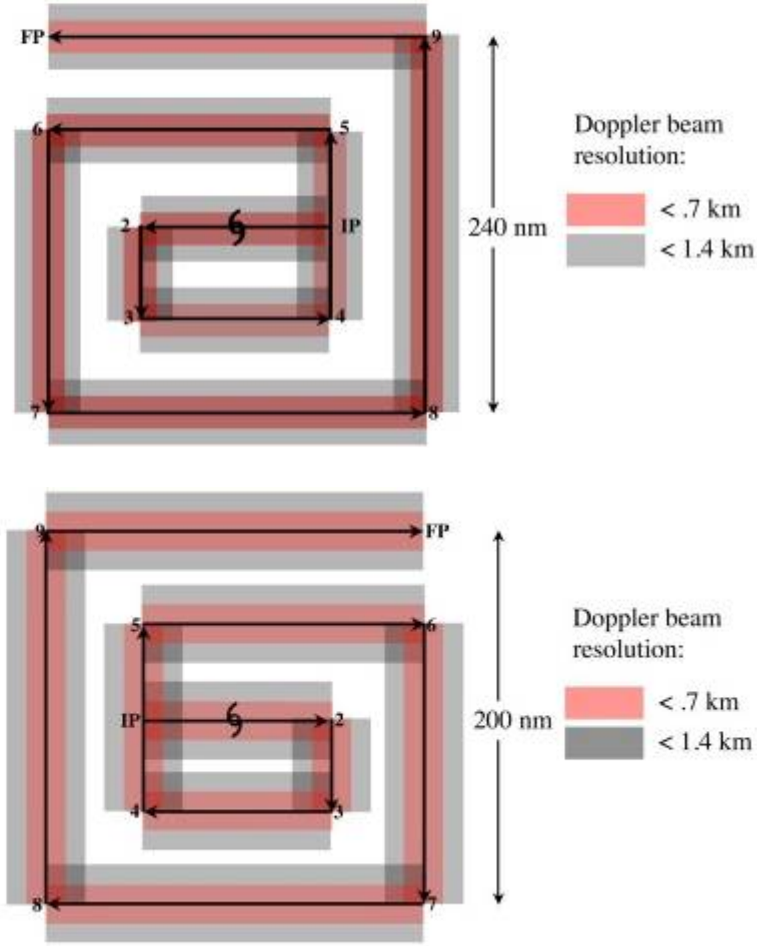


Figure 1-3: Doppler radar coverage for box-spiral pattern with 200- (top) and 240- (bottom) nm legs. Pink region shows areas where vertical beam resolution is better than 0.7 km and gray regions delineate areas where vertical beam resolution is better than 1.4 km. Maximum extent of gray area is approximately 40 km from flight track, approximately the maximum usable extent of reliable airborne Doppler radar coverage. Upper pattern is 1500 nm and uses 6.25 hours, while lower pattern is 1250 nm and uses 5.2 hours.

Note 1. Pattern flown where even coverage is required, particularly in tropical depressions and tropical storms. Doppler radars should be operated in single-PRF mode, at a PRF of 2100. Radar scientist should verify this mode of operation with AOC engineers. If there is no assigned radar scientist, LPS should verify. *This is crucial for the testing and implementation of real-time quality control.*
Note 2. Assure that transmitter is switching between fore and aft antennas, by examining the real time display.
Note 3. IP can be at any desired heading relative to storm center
Note 4. To maximize dropwindsonde coverage aircraft should operate at highest altitudes that still minimize icing.
Note 5. Maximum radius may be decreased or increased within operational constraints.
Note 6. Dropwindsondes are not a required part of this flight plan and are optional.
Note 7. Maximum radius may be changed to meet operational needs while conforming to flight-length constraints.
Note 8. If dropwindsondes are not deployed, aircraft can operate at any level below the melting level, with 10,000 ft preferred. Aircraft might also fly lower, if circulation not evident at 10,000 ft.

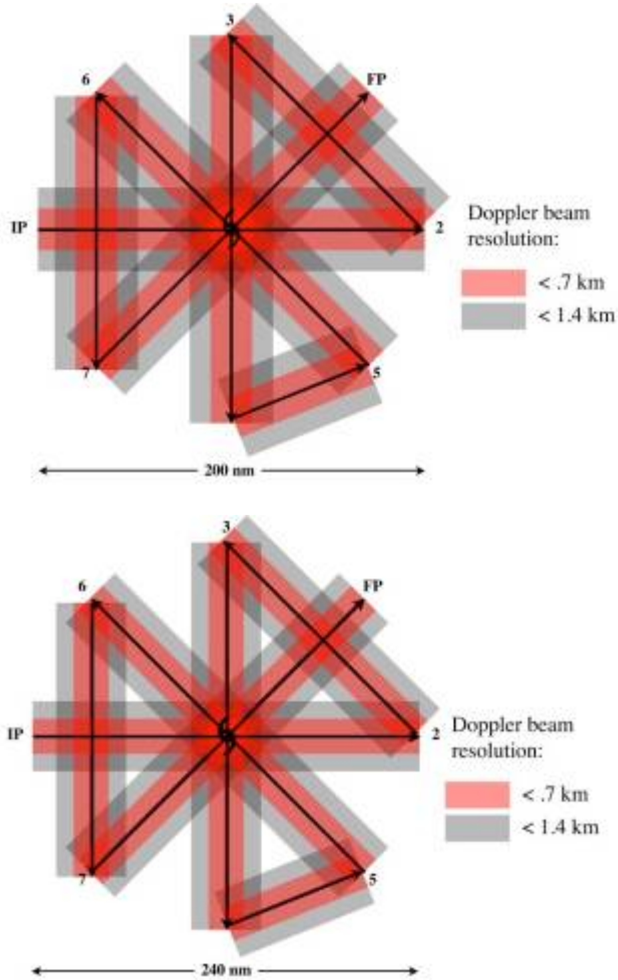


Figure 1-4: Doppler radar coverage for radial extents of 100 (top) and 120 (bottom) nm of the rotating figure-4 patterns. Pink region shows areas where vertical beam resolution is better than 0.7 km and gray regions delineate areas where vertical beam resolution is better than 1.4 km. Maximum extent of gray area is approximately 40 km from flight track, approximately the maximum usable extent of reliable airborne Doppler radar coverage. Flight distances for 100, 120 and 150 nm radial extents are 1160, 1395, and 1745 nm. Corresponding flight times are: 4.8, 5.8, and 7.3 h.

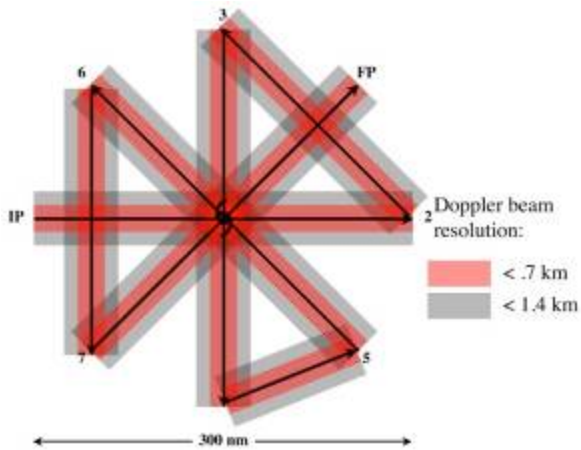
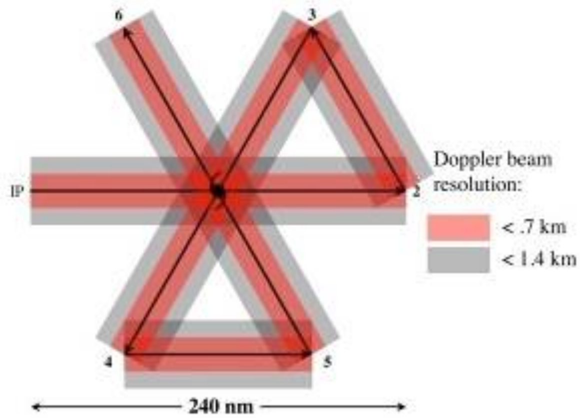


Figure 1-4 (continued): Doppler radar coverage for 150-nm legs for a rotating figure-4. Flight distances for 100, 120 and 150 nm radial extents are 1160, 1395, and 1745 nm. Corresponding flight times are: 4.8, 5.8, and 7.3 h.

Note 1. This pattern should be flown in strong tropical storms and hurricanes, where the circulation extends from 100 nm to 150 nm from the center. Doppler radars should be operated in single-PRF mode, at a PRF of 2100. Radar scientist should verify this mode of operation with AOC engineers. If there is no assigned radar scientist, LPS should verify. *This is crucial for the testing and implementation of real-time quality control.*
Note 2. Assure that transmitter is switching between fore and aft antennas, by examining the real time display.
Note 3. IP can be at any desired heading relative to storm center
Note 4. To maximize dropwindsonde coverage aircraft should operate at highest altitudes that still minimize icing
Note 5. Maximum radius may be decreased or increased within operational constraints
Note 6. Dropwindsondes shown are not a required part of this flight plan and are optional.
Note 7. Flight pattern should be centered around either the 03, 09, 15, or 21 UTC so Doppler observations are available for both surrounding observation periods.
Note 8. Maximum radius may be changed to meet operational needs while conforming to flight-length constraints.



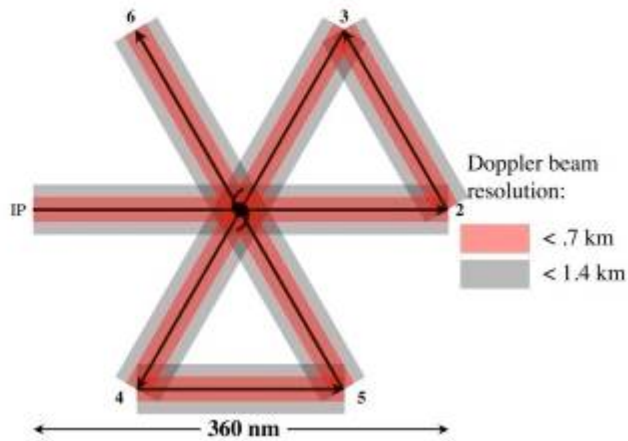


Figure 1-5: Doppler radar coverage for 120- (top) and 180- (bottom) nm legs for the Butterfly pattern. Pink region shows areas where vertical beam resolution is better than 0.75 km and gray regions delineate areas where vertical beam resolution is better than 1.5 km. Maximum extent of gray area is approximately 40 km from flight track, approximately the maximum usable extent of reliable airborne Doppler radar coverage. Flight distances for the patterns with 120 and 180 nm radials legs are 960 and 1440 nm. Corresponding flight durations are 4 and 6 h.

Note 1. This pattern will be flown in large tropical storms, as well as hurricanes. Doppler radars should be operated in single-PRF mode, at a PRF of 2100. Radar scientist should verify this mode of operation with AOC engineers. If there is no assigned radar scientist, LPS should verify. *This is crucial for the testing and implementation of real-time quality control.*
Note 2. Assure that transmitter is switching between fore and aft antennas, by examining the real time display.
Note 3. IP can be at any desired heading relative to storm center
Note 4. To maximize dropwindsonde coverage aircraft should operate at highest altitudes that still minimize icing
Note 5. Maximum radius may be decreased or increased within operational constraints
Note 6. Dropwindsondes are not a required part of this flight plan and are optional.
Note 7. Flight pattern should be centered around either 03, 09, 15, or 21 UTC so Doppler observations are available for both surrounding observation periods.
Note 8. Maximum radius may be changed to meet operational needs while conforming to flight-length constraints.

Three-Dimensional Doppler Winds

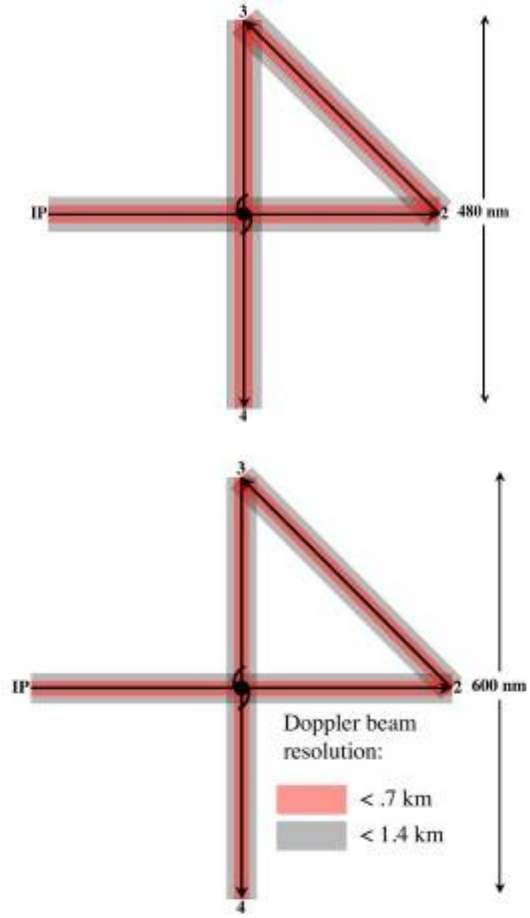


Figure 1-6: Doppler radar coverage for 300-nm legs for a single figure-4 pattern. Pink region shows areas where vertical beam resolution is better than 0.75 km and gray regions delineate areas where vertical beam resolution is better than 1.5 km. Maximum extent of gray area is approximately 40 km from flight track, approximately the maximum usable extent of reliable airborne Doppler radar coverage. Flight distances for radial extents of 240 and 300 nm are 1300 and 1645 nm, respectively. Corresponding flight times are 5.4 and 6.8 h.

Note 1. Pattern for large storms, to obtain as full a radial extent of observations of the full storm circulation as possible. Doppler radars should be operated in single-PRF mode, at a PRF of 2100. Radar scientist should verify this mode of operation with AOC engineers. If there is no assigned radar scientist, LPS should verify. *This is crucial for the testing and implementation of real-time quality control.*
Note 2. Assure that transmitter is switching between fore and aft antennas, by examining the real time display.
Note 3. IP can be at any desired heading relative to storm center
Note 4. To maximize dropwindsonde coverage aircraft should operate at highest altitudes that still minimize icing
Note 5. Maximum radius may be decreased or increased within operational constraints
Note 6. Dropwindsondes are not a required part of this flight plan and are optional.
Note 7. Flight pattern should be centered around either the 03, 09, 15, or 21 UTC so Doppler observations are available for both surrounding observation periods.
Note 8. Maximum radius may be changed to meet operational needs while conforming to flight-length constraints.