EXPERIMENT DESCRIPTION
9. Tropical Cyclogenesis Experiment

Principal Investigator(s): Robert Rogers, Paul Reasor, and Wallace Hogsett (NHC)

Links to IFEX:
It supports the following NOAA IFEX goals:

- **Goal 1:** Collect observations that span the TC lifecycle in a variety of environments;
- **Goal 3**: Improve understanding of the physical processes important in intensity change for a TC at all stages of its lifecycle;

Motivation:
While forecasts of TC track have shown significant improvements in recent years (Aberson 2001), corresponding improvements in forecasts of TC intensity have been much slower (DeMaria and Gross 2003). The lack of improvement in intensity forecasting is the result of deficiencies in the numerical models (e.g., resolution limitation and parameterization inadequacies), deficiencies in the observations, and deficiencies in basic understanding of the physical processes involved. The problem becomes even more acute for forecasting tropical cyclogenesis. While global models have shown some skill in recent years in predicting tropical cyclogenesis, understanding of the physical processes involved remains limited, largely because observing genesis events is a difficult task. However, a key aspect of IFEX (Rogers et al. 2006) is the collection of observations during all portions of a TC lifecycle, particularly on the early lifecycle stages. This emphasis on the early stages of the lifecycle will provide an opportunity to observe several genesis events and improve understanding of this key process, leading to better predictions of tropical cyclogenesis, organization, and intensification.

Since both tropical cyclogenesis and TC intensity change can be defined by changes in low- and mid-level vorticity, knowledge of the processes that play a significant role in genesis will also advance understanding of intensity change. A better understanding of the processes that lead to an increase in low- and mid-level cyclonic vorticity will also allow NHC to better monitor and forecast tropical cyclogenesis and intensity change, improvements that would be especially valuable for those events that threaten coastal areas. Data obtained by aircraft investigating potential genesis events will positively impact operations and research in other ways as well. The collection of three-dimensional data at all stages in a TC lifecycle is one of the key requirements for NCEP as a part of IFEX. Such data will provide information that will guide the development of error covariances important in the development of data assimilation schemes for models (i.e., HWRF) that will be used in these environments. They will also provide important datasets for evaluating the performance of HWRF. In addition to improving the understanding and forecasting of tropical cyclogenesis and intensity change, the proposed experiment will yield useful insight into the structure, growth and ultimately the predictability of the systems responsible for almost all of the weather-related destruction in the tropical Atlantic and East Pacific. Investigation of systems that fail to complete the genesis process will 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.

Background:
Tropical cyclogenesis can be viewed as a rapid increase of low-level cyclonic vorticity organized on the mesoscale within a region of enhanced convective activity. Numerous hypotheses have been advanced in the literature to explain how this vorticity develops and amplifies. One of the key aspects differentiating these hypotheses centers on whether the lower-tropospheric cyclonic

vorticity begins in the mid-levels and develops downward to the surface or begins in the lower troposphere and builds upward to the middle troposphere – the so-called top-down vs. bottom-up mechanisms. Prominent top-down theories include one study which showed observations of multiple midlevel vortices prior to genesis in the West Pacific (Ritchie et al. 1997) that led them to view the genesis process as a stochastic one whereby chance merger and axisymmetrization of these midlevel vortices leads to growth of the circulation to the surface by increasing the Rossby-Prandtl-Burger penetration depth of potential vorticity anomalies associated with the vortices. Another study supporting the top-down approach showed observations of genesis in the East Pacific (Bister and Emanuel 1997) and hypothesized that downdrafts driven by evaporational cooling advected the vorticity of the midlevel vortex downward, enhancing convection and low-level vorticity production.

The set of hypotheses supporting the bottom-up approach generally describes the genesis process as being driven by low-level convergence that increases cyclonic vorticity near the surface through vortex stretching. One such bottom-up hypothesis emphasizes the role of a parent midlevel vortex in axisymmetrizing nearby low-level convectively generated cyclonic vorticity, called vortical hot towers, that leads to the spin-up of the surface circulation (e.g., Montgomery and Enagonio 1998; Davis and Bosart 2001; Hendricks et al 2004). A similar hypothesis was advanced by Rogers and Fritsch (2001) and Chen and Frank (1993) who emphasized the role of the midlevel vortex and high midlevel humidity in providing a favorably reduced local Rossby radius of deformation to retain the heating from convective bursts and spin up low-level vorticity through low-level stretching caused by the convective heating. The importance of convective heating and divergence profiles for the development of low-level vorticity has been shown in the Doppler radar observations of Tropical Storm Dolly by Reasor et al. (2005) and Hurricane Ophelia by Houze et al. (2009) and in numerical simulations of the genesis of Tropical Storm Gert by Braun et al. (2010) and the rapid intensification of Hurricane Dennis in Rogers (2010). Another set of genesis theories focuses on the reduction of the lower tropospheric effective static stability to low values in the core of incipient cyclones. Suppression of convectively induced downdrafts is one means of accomplishing this (Emanuel 1995; Raymond, Lopez-Carrillo, and Lopez Cavazos 1998). Eliminating low-level outflows produced by the downdrafts allows the inflow of updraft air to spin up the low-level circulation, leading to the development of the warm-core characteristic of the TC.

Finally, it has been shown in Dunkerton, Montgomery and Wang (2009, DMW09) and Wang, Montgomery and Dunkerton (2009, WMD09) that genesis tends to occur near the intersection of a tropical wave critical surface and the precursor parent wave's axis, which is the center of a "pouch". This "marsupial" paradigm suggests that the critical layer of a tropical easterly wave is important to tropical storm formation because 1) wave breaking or roll-up of the cyclonic vorticity near the critical surface in the lower troposphere provides a favored region for the aggregation of vorticity seedlings and TC formation; 2) the wave critical layer is a region of closed circulation, where air is repeatedly moistened by convection and protected from dry air intrusion; and 3) the parent wave is maintained and possibly enhanced by diabatically amplified mesoscale vortices within the wave.

Hypotheses:

With the above background in mind, the following hypotheses will be tested by data collected and analyzed here:

1. <u>Tropical cyclogenesis is primarily a bottom-up process that requires a broad area of convective processes in concert with stratiform precipitation</u>

This hypothesis will be tested by documenting the development of low-level vorticity in the presence of a midlevel vortex center, and vice versa, as well as by documenting the interactions between low- and mid-level vortices in pre-genesis environments. It will also consider the precipitation structures within the developing circulation and how these structures (convective vs. stratiform) evolve over time.

2. The interaction of an incipient vortex with the Saharan Air Layer (SAL) overall is detrimental for tropical cyclogenesis.

Key tasks in testing this hypothesis involve collecting temperature, humidity, pressure, and wind measurements across multiple scales, i.e., within the core and near environment of an incipient vortex. These measurements will be key to assessing the importance of pre-existing vorticity and broad areas of high humidity on the maintenance of deep convection in the incipient vortex and determining the importance of their spatial and temporal distribution in tropical cyclogenesis. Another important question to address is the importance of downdraft suppression in limiting boundary layer stabilization. A final, and key, task is to examine hypotheses relating humidity and static stability profiles to downdraft morphology and the vortex response to convective heating, in particular in the presence of dry air and lower-tropospheric shear typically associated with SAL interactions.

3. As stated in DMW08 and WMD09, genesis tends to occur near the intersection of a tropical wave critical surface and the precursor parent wave's axis, which is the center of a "pouch".

The objective of marsupial tracking is to track the wave pouch (rather than the diabatic vortices inside the pouch) and estimate its propagation speed and predict the genesis location, which can be used to provide useful guidance for flight planning during IFEX.

4. Convective systems that ingest low-level flow rich in helicity preferentially produce low-level cyclonic vorticity and accelerate near-surface spin-up.

MCSs that exhibit a deep convective line and an adjacent stratiform region are symptomatic of a locally vertically-sheared environment. Depending on the vertical profile of the near-MCS horizontal winds, updraft-shear interactions may result in preferential generation of cyclonic vorticity. To test the hypothesis, the vertical profile of horizontal winds in the immediate vicinity of the leading convective line, with a focus on low-level inflow, will be sampled.

Experiment Description:

The physical processes that are important in tropical cyclogenesis span a wide spectrum of temporal and spatial scales, with time scales ranging from minutes to days and space scales ranging from mm to hundreds of km. Furthermore, many of the processes are highly nonlinear and transient. For these reasons, an experimental approach that combines observations and numerical modeling is required to adequately address the questions posed above. What is discussed here is the observational component of GenEx. When possible, GenEx missions will be coordinated with SALEX. This coordination will involve the P-3 and/or G-IV and be executed on a case-by-case basis.

Recent observations from airborne Doppler radar have identified important processes on the mesoscale that contribute to tropical cyclogenesis. For example, results obtained from a P-3 aircraft investigation of Dolly in 1996 (Reasor et al. 2005) indicate its genesis was strongly influenced by persistent, deep convection in the form of mesoscale convective systems (MCSs) that developed in association with an easterly wave over the Caribbean. Within this deep convection an eye-like feature formed, after which time the system was declared a depression. The initial development of the low-level circulation in both Dolly (1996) and Guillermo (1991) occurred in the presence of multiple midlevel vortices. The close proximity of the low- and mid-level vorticity maxima (often within 50-100 km horizontally) observed in these two genesis cases supports a further examination of the aforementioned vortex merger ideas. To adequately diagnose the role of these vortices, it is vital that they be sampled in their entirety (which will invariably depend on the distribution of precipitation scatterers) and with a temporal resolution that allows time continuity of the vortices to be established when possible.

In addition to the wind and rainfall measurements provided by the Doppler radars, measurements of temperature and moisture are vital to address the thermodynamic issues described above. Dropwindsondes released in a regular grid will enable the determination of thermodynamic fields in the vicinity of the incipient system, as well as enable the calculation of mean divergence and vorticity fields around the system, important in determining the strength and depth of the downdrafts (provided time aliasing is minimized). The dropwindsondes should be released from as high an altitude as possible to provide observations of mid-level humidity and wind speeds where scatterers are not present. The tail radars on the P-3s will also enable a determination of the presence of saturation when scatterers are observed.

This may be executed with the P-3 alone, but optimally it will involve the participation of the NOAA G-IV aircraft as well. Flights will occur into incipient tropical disturbances over the western Caribbean Sea, Gulf of Mexico, and tropical Atlantic Ocean. For these missions the P-3's may be based in Tampa, St. Croix, or Barbados. The systems flown here will primarily be incipient systems. To minimize the potential of land interactions, no system will be targeted that has the potential of making landfall within 48 h of the beginning of the first flight. Also, no system will be targeted that does not have the likelihood of being a viable target for at least three consecutive P-3 missions (i.e., 24 h), with four P-3 missions or more being considered optimal.

The primary mission will require the P-3 flying back-to-back missions. It will fly mesoscale survey patterns designed to document any suspected low- and mid-level vortices and sample any changes in the low- and mid-level thermodynamic fields associated with the incipient systems. Crucial to a complete understanding of the genesis process is the collection of observations with high temporal and spatial resolution. In anticipation of future operational missions required at synoptic times (12 and 00 UTC) as the incipient system intensifies, the staggered P-3 missions are designed to commence on station at 12 and 00 UTC, meaning that takeoff would be around 09 and 21 UTC, respectively. If it is not possible to fly the P-3 at 12-h staggering, then 24-h staggering will be performed. If available, the G-IV aircraft would fly simultaneously at upper levels (42,000 ft or 175 hPa).

The main aircraft for the mesoscale flights will be the P-3. Doppler radar observations, dropwindsondes, and flight-level observations obtained during these flights will help locate low- and mid-level vortices and help document their structures and life cycles. Primary aspects will be to observe the complete life cycle and interaction of low- and mid-level vortices, understand how these vortices are influenced by the diurnal cycle of convection, and observe the evolution of the thermodynamic fields as the incipient system evolves. The location of persistent areas of deep convection and candidate vortices will be determined using high-resolution visible and infrared GOES-winds produced available online, supplemented by satellite microwave imagery when available. Additionally, favorable environments for deep convection and vortex development, such as those described in the Introduction, will be identified using water vapor loops, model analysis fields enhanced by satellite wind measurements, and possibly ASCAT imagery, also available online.

Staggered missions with the P-3 aircraft will begin with the aircraft flying one of two survey patterns at max 12,000 ft (4 km). The primary purpose of these patterns will be to collect F/AST Doppler radar and dropwindsonde 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. Two possible patterns can be flown, with the decision of which pattern determined by the degree of organization of the system. For incipient systems that are relatively disorganized, a lawnmower pattern is flown (Fig. 5-1) along the axis of an easterly wave. Leg lengths will be 150-200 nm (250-300 km), with some variability dependent on the size of the system and the time available on station. The pattern will be centered approximately on any discernible circulation or wave axis, if identifiable, or in the absence of such features, on a dominant area of convective activity. Priority will be placed, however, on centering the pattern on the mesoscale circulation pattern (i.e., the pouch), and *not* targeted at transient convective activity.

As a system becomes better organized, a second survey pattern is flown (Fig. 5-2), consisting of a square-spiral centered on a broad low- or mid-level circulation center. If multiple mesoscale convective systems exist embedded within a parent circulation, the pattern will be centered on the parent circulation. Dropwindsondes are released at regular intervals to create a near uniform grid covering the circulation and including any MCSs, if possible. The spacing between the outer spiral and the inner box pattern is nominally set for 60 nm (111 km), but it can be varied to ensure optimal representation of the convective and mesoscale features.

Once a persistent low-level vortex is identified, subsequent missions will include a rotating figure-4 pattern (Fig. 5-3) centered on the vortex. Flight legs will be 60-120 nm (111-225 km) to allow for the collection of data with high temporal and spatial resolution in the vicinity of the vortex center. The length of these flight legs is designed to completely include the low-level vortex and convection associated with it. Depending on the leg lengths and the time available on station, the pattern may consist of higher azimuthal resolution. The tail radar will operate in F/AST mode during the entirety of these patterns.

If available, the G-IV will fly a synoptic pattern at maximum altitude to observe the troposphere with dropwindsondes in the pre-genesis and incipient tropical disturbance environment. The most likely scenario calls for the G-IV to fly a star pattern to sample and possible interaction of the system with a SAL (e.g. as depicted in Fig. 5-5).

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

Option 1 (Optimal experiment):

The optimal experiment is when the P-3 aircraft will fly in the tropical Atlantic, Gulf of Mexico, or western Caribbean basins, either lawnmower or square-spiral survey patterns to locate low- and mid-level vortices (Figs. 5-1 or 5-2). These flights will be flown in coordination with the G-IV aircraft, providing synoptic-scale measurements of upper- and lower-tropospheric observations around the incipient disturbance (Fig. 5-5b and SALEX description). Once a persistent mid-level vortex is located, the P-3 will fly either rotating figure-4 (Fig. 5-3) or square-spiral patterns. The lesser experiment is only with the P-3.

NASA will be conducting their Hurricane Severe Storm Sentinel (HS3) mission from Sept. 1 – Oct. 5. This mission will consist of two unmanned Global Hawk (GH) aircraft, flying at approximately 60,000 ft altitude with mission durations of up to 30 h. One GH will focus on flying patterns over the inner-core of tropical cyclones, while the other GH will focus on patterns in the environment of TC's. The primary science goals of HS3 are to better understand inner-core and environmental processes important in TC genesis, intensification, and extratropical transition.

When possible, it will be desirable to fly patterns with the NOAA aircraft that are coordinated with the GH aircraft. For the NOAA P-3, "coordinated" means flying legs where the P-3 and GH are vertically-stacked for at least a portion of the flight leg. Both the inner-core and environmental GH can fly patterns that are similar in geometry to the NOAA P-3 patterns, including lawnmower (Fig. 6), square-spiral (Fig. 7), and figure-4 type patterns (Fig. 8). The across-track displacement during such coordination should be kept as small as practicable, e.g., no greater than 5-10 km. In practice, the NOAA P-3 will likely fly its patterns as indicated in Fig. 1-3. To achieve coordination the inner-core GH would align its legs such that the GH will be stacked with the P-3. It is likely that not all of these aircraft will be flying simultaneously; rather, efforts will be made to have an aircraft either in the inner core or the environment at all times.

Convective Burst Module:
This is a stand-alone module that takes one hour or less to complete. Execution is dependent on system attributes, aircraft fuel and weight restrictions, and proximity to operations base. The objectives are to obtain quantitative description of the kinematic, thermodynamic, and electrical properties of intense convective systems (bursts) and the nearby environment to examine their role in the cyclogenesis process. It can be flown separately within a mission designed to study local areas of convection or at the end of one of the survey patterns. Once a local area of intense convection is identified, the P-3 will transit at altitude (12,000 ft.) to the nearest point just outside of the convective cores and fly a circumnavigation of the convective area (Fig. 5-4). The circumnavigation will consist of a series of straight legs just outside of the main convection. The tail radar should be operated in F/AST sector scan and regularly spaced dropwindsondes (10-20 km apart) will be released during this time. While flying parallel to the leading convective line, dropwinsonde deployment should occur as close to the leading line as is safely possible. Once the circumnavigation is completed, and the P-3 is near the original IP, two straight-line crossings of the convective area should be performed with the P-3 avoiding the strongest cores, as necessary for safety considerations. The P-3 should fly at a constant altitude of 12,000 ft – radar or pressure altitude is fine. If time permits, the P-3 should descend to the lowest safe altitude and perform another circumnavigation (or partial one) of the convective burst. No dropwindsondes will be released during the low-level run.

Pouch Module:
This is a two-plane mission coordinated between the P-3 and G-IV, designed to monitor a potentially developing tropical wave. The P-3 will fly a survey pattern (diamond or square-spiral) within the pouch, as diagnosed by examining tropical wave-relative lower-tropospheric flow (Fig. 5-5b). If there is an organized area of deep convection present within the pouch, the P-3 will break off from the survey pattern to perform a convective burst module. Priority is placed on performing at least one convective burst module, even at the expense of completing the survey pattern if time is limited. The G-IV will fly a star pattern with triangular legs that extend to the edge of the pouch in each quadrant of the storm. On the inbound legs the G-IV will extend inward to the edge of the cold cloud shield, as safety permits, and fly a leg tangential to the system before extending back outward for the next triangular portion of the pattern. Dropsondes from the P-3 will be launched at each turn point in the pattern plus the midpoints of the legs, provided there is no overlap with previous drop locations. Dropsondes from the G-IV will be launched at all turn points and the midpoints of the radial legs.

Analysis strategy:

As discussed above, airborne Doppler, dropwindsonde, and flight-level data will be critical datasets for the documenting of the evolution of the wind, temperature, and humidity field during this experiment. Analyses of the three-dimensional wind field from the Doppler radar will identify circulation at multiple altitudes (where scatterers are present), while the dropsonde data will measure the temperature and humidity fields in the lower troposphere. Flight-level data will also be useful for measuring winds, temperature, and moisture. As a circulation center becomes defined, decomposition of the variables into symmetric and asymmetric components will be performed to document the vortex evolution. Precipitating areas will be partitioned into convective and stratiform regions, and statistics (e.g., CFADs) of vertical velocity and reflectivity will be calculated for these regions from the Doppler data to document the evolution of convective-scale features during the genesis process. Data from multiple aircraft can be included to create a synthesis of measurements spanning multiple scales and the entire lifecycle.

In addition to testing the hypotheses stated above, this multiscale, near-continuous dataset will prove valuable in evaluating high-resolution model simulations (i.e., HWRFx) of tropical cyclogenesis.

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Tropical Cyclogenesis Experiment

Principal Investigator(s): Robert Rogers,Paul Reasor, and Wallace Hogsett (NHC)

Objective: To sample the wind, temperature, and moisture fields within and around a tropical disturbance that has the potential to develop into a tropical depression.

What to Target: A tropical wave or organized area that has shown a history of persistent deep convection (convection may not be active at time of takeoff).

When to Target: When system is early in its development into a tropical depression.

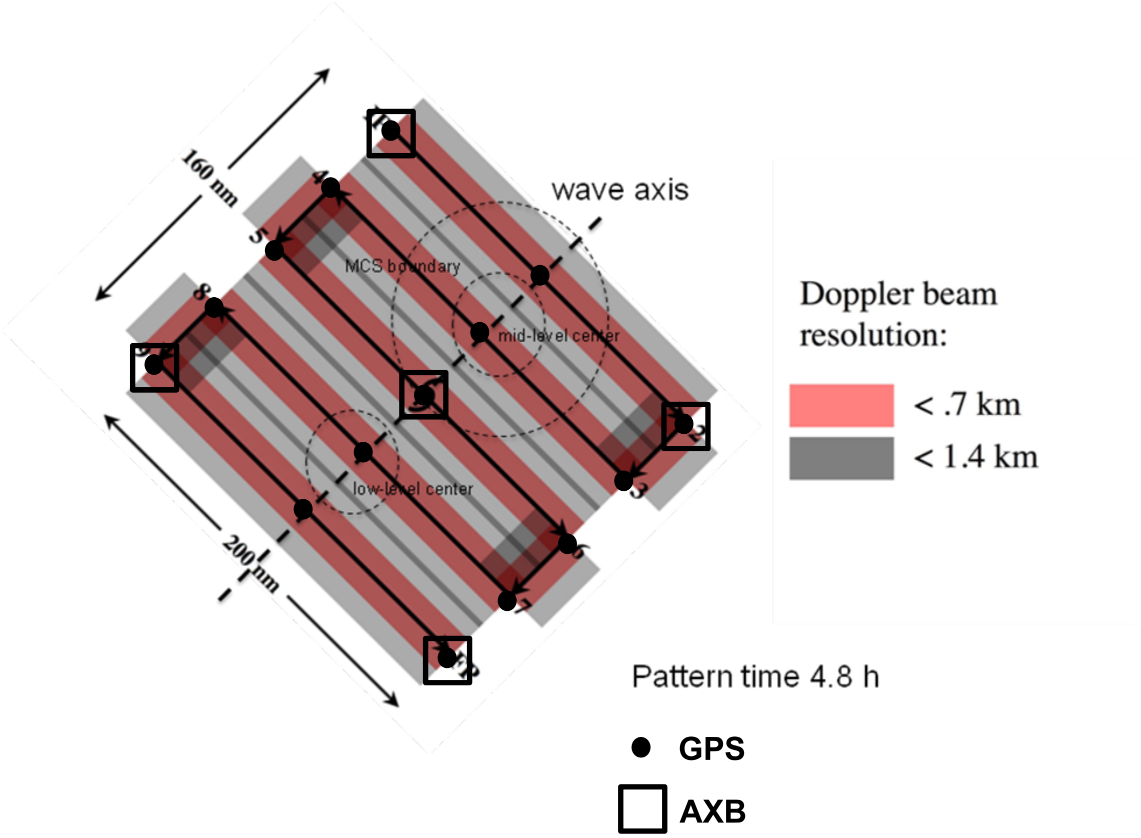


Figure 9-1: P-3 Pre-genesis early organization vortex survey pattern – Lawnmower pattern.

- Altitude: 12,000 ft (4 km) altitude preferable.
- Expendables: Deploy dropwindsondes at all turn points and midway along long legs. If available, deploy AXBT's at outer corners and center of pattern, coincident with dropsondes. No more than 24 GPS drops, 8 AXBT's needed.
- Pattern: The pattern is flown with respect to the wave axis, typically inclined at 30-40° from N, or relative to circulation or vorticity centers. Length of pattern (axis parallel to wave axis) should cover both low- and mid-level vortices, leg lengths range from 150 – 200 nm (275-375 km). Leg lengths and separation distance can vary, depending on storm size and ferry time.
- Instrumentation: Set airborne Doppler radar to scan F/AST on all legs.

Tropical Cyclogenesis Experiment

Principal Investigator(s): Robert Rogers,Paul Reasor, and Wallace Hogsett (NHC)

Objective: To sample the wind, temperature, and moisture fields within and around a tropical disturbance that has the potential to develop into a tropical depression.

What to Target: A tropical wave or organized area that has shown a history of persistent deep convection (convection may not be active at time of takeoff).

When to Target: When system is later in its development into a tropical depression.

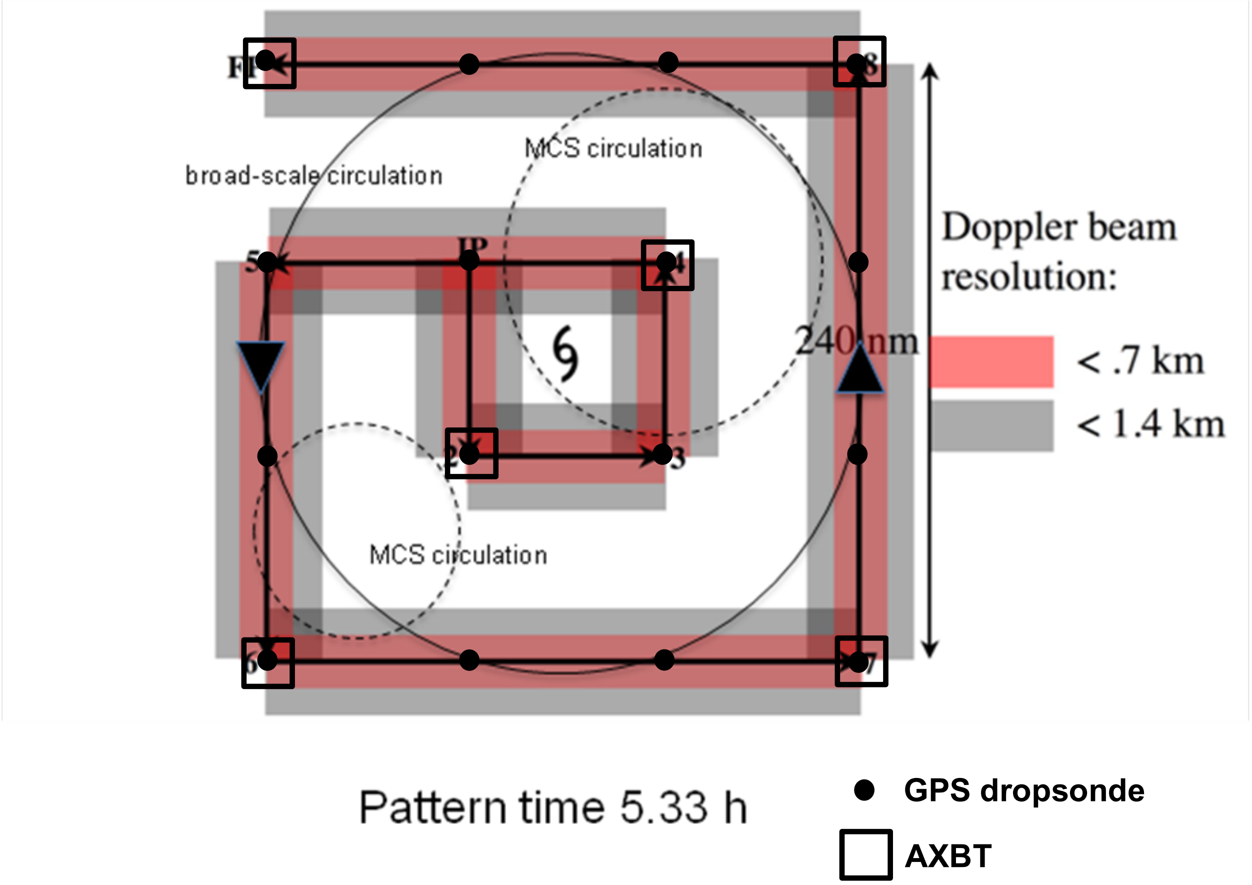


Figure 9-2: P-3 Pre-genesis late organization vortex survey pattern – Square-spiral pattern.

- Altitude: 12,000 ft (4 km) altitude preferable.
- Expendables: Release dropwindsondes at all numbered points. Releases at intermediate points can be omitted if dropwindsonde supply is insufficient. If available release AXBT's at outer corner locations and at two corner locations in inner square, coincident with dropwindsondes. No more than 24 GPS drops, 8 AXBT's needed.
- Pattern: The spacing between the outer spiral and inner box (nominally set to 60 nm (111 km)) can be increased or decreased depending on the size of the disturbance and ferry time.
- Instrumentation: Set airborne Doppler radar to scan F/AST on all legs.

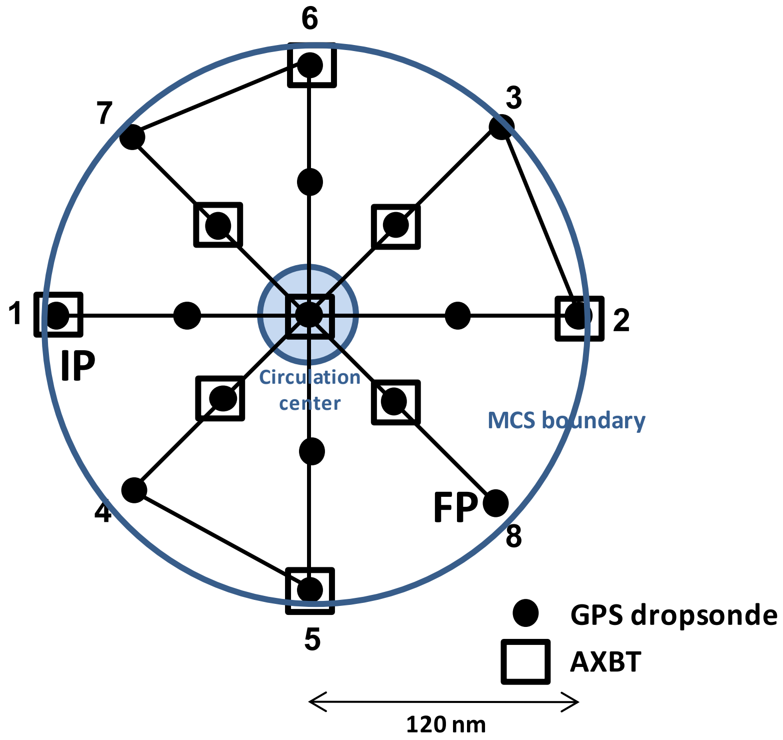
Tropical Cyclogenesis Experiment

Principal Investigator(s): Robert Rogers,Paul Reasor, and Wallace Hogsett (NHC)

Objective: To sample the wind, temperature, and moisture fields within and around a tropical disturbance that has the potential to develop into a tropical depression.

What to Target: A tropical depression or tropical storm (convection likely to be active at time of takeoff).

When to Target: During tropical depression stage, or if the tropical storm is in the early stage of its development.



Pattern time: ~5.0 h

Figure 9-3: P-3 Post-genesis rotating figure-4 pattern.

- Altitude: 12,000 ft (4 km) altitude preferable.
- Expendables: Release dropsondes at turn points, midpoint of radial legs, and on the first and last center pass. If available, drop AXBT's at points 1, 2, 5, and 6, at midpoints of leg 3-4 (both inbound and outbound), at midpoints of leg 7-8 (both inbound and outbound), and on first center pass. All AXBT's should be released coincident with dropsondes.
- Pattern: Fly 1-2-3-4-5-6-7-8 at 12,000 ft altitude, 60-120 nm (111-225 km) leg length. The pattern may be entered along any compass heading.

- Instrumentation: Set airborne Doppler radar to scan F/AST on all legs.

Tropical Cyclogenesis Experiment

Principal Investigator(s): Robert Rogers,Paul Reasor, and Wallace Hogsett (NHC)

Objective: To sample the wind, temperature, and moisture fields within and around a tropical disturbance that has the potential to develop into a tropical depression.

What to Target: An area of vigorous, deep convection occurring within the circulation of a developing tropical disturbance.

When to Target: When deep convection is identified either by radar or satellite during the execution of a GenEx pattern.

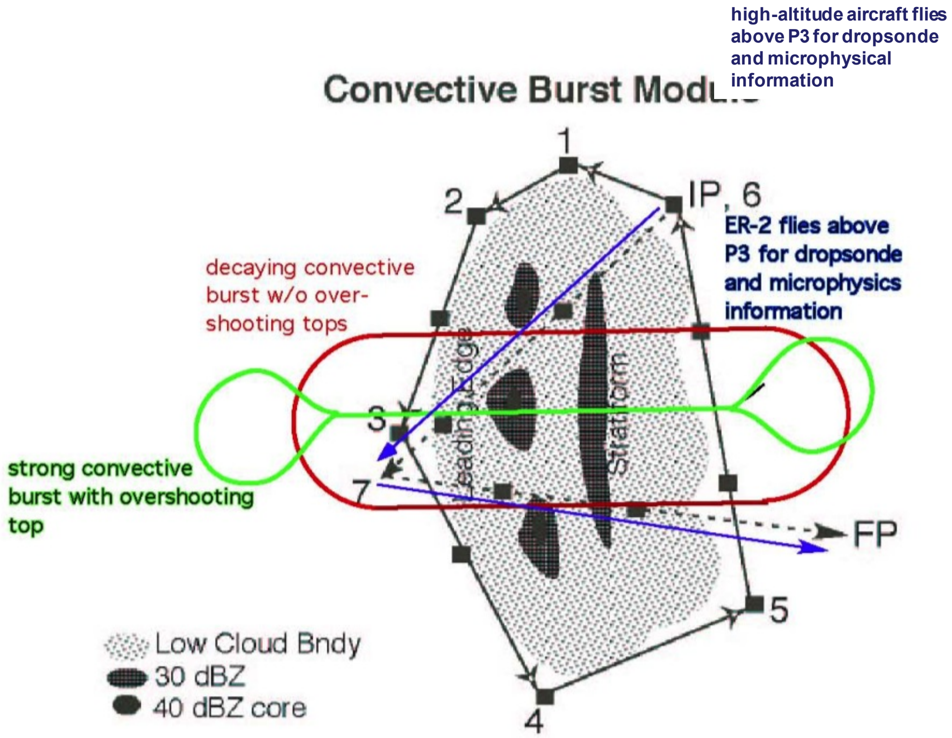


Figure 9-4: P-3 Convective burst module.

- Altitude: 12,000 ft (4 km) altitude preferable.
- Expendables: Release dropsondes at turn points and at intermediate points as indicated in Figure. Additionally, release 1-2 drops during penetration of convective system. No more than 15 dropsondes needed for this module.
- Pattern: Circumnavigation (IP to point 6) by single P-3. Then fly convective crossing (6-7-FP). Repeat circumnavigation (time permitting) at low altitude (1500-2500 ft

depending on safety constraints). If available, high-altitude aircraft (e.g., ER-2 or Global Hawk) flies either racetrack or bowtie pattern during P-3 circumnavigation, flies vertically aligned with P-3 during convective crossing

- Instrumentation: Set airborne Doppler radar to scan F/AST on all legs.

Tropical Cyclogenesis Experiment

Principal Investigator(s): Robert Rogers, Paul Reasor, and Wallace Hogsett (NHC)

Objective: To sample the wind, temperature, and moisture fields within and around a tropical disturbance that has the potential to develop into a tropical depression.

What to Target: The environment of a tropical wave or organized area that has shown a history of persistent deep convection, or a tropical depression.

When to Target: Any time prior to or just after designation of system as a tropical depression.

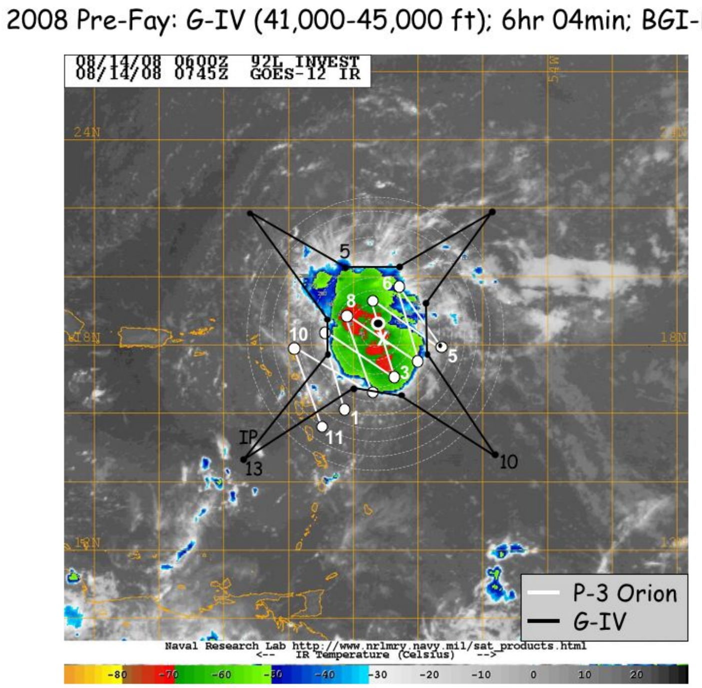


Figure 9-5: G-IV Pouch module.

- Altitude: 41-45,000 ft.
- Pattern: G-IV flies as close to cold cloud shield on inner radii as is deemed safe.
- Expendables: Release G-IV drops at all turn points and midpoints of radial legs.

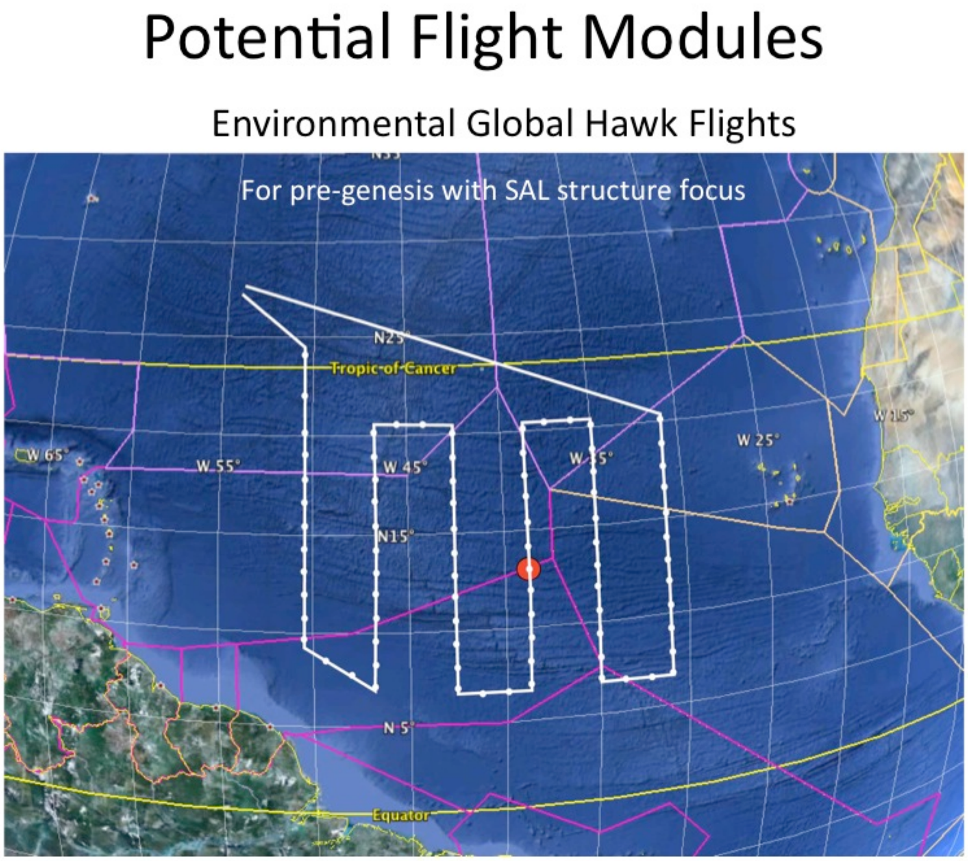
Tropical Cyclogenesis Experiment

Principal Investigator(s): Robert Rogers,Paul Reasor, and Wallace Hogsett (NHC)

Objective: To sample the wind, temperature, and moisture fields within and around a tropical disturbance that has the potential to develop into a tropical depression.

What to Target: A tropical depression or tropical storm (convection likely to be active at time of takeoff).

When to Target: During tropical depression stage, or if the tropical storm is in the early stage of its development.


Potential Flight Modules

Environmental Global Hawk Flights

For pre-genesis with SAL structure focus

Figure 9-6. Sample lawnmower flight pattern for GH over a developing TC in the central Atlantic.

Tropical Cyclogenesis Experiment

Principal Investigator(s): Robert Rogers,Paul Reasor, and Wallace Hogsett (NHC)

Objective: To sample the wind, temperature, and moisture fields within and around a tropical disturbance that has the potential to develop into a tropical depression.

What to Target: A tropical depression or tropical storm (convection likely to be active at time of takeoff).

When to Target: During tropical depression stage, or if the tropical storm is in the early stage of its development.

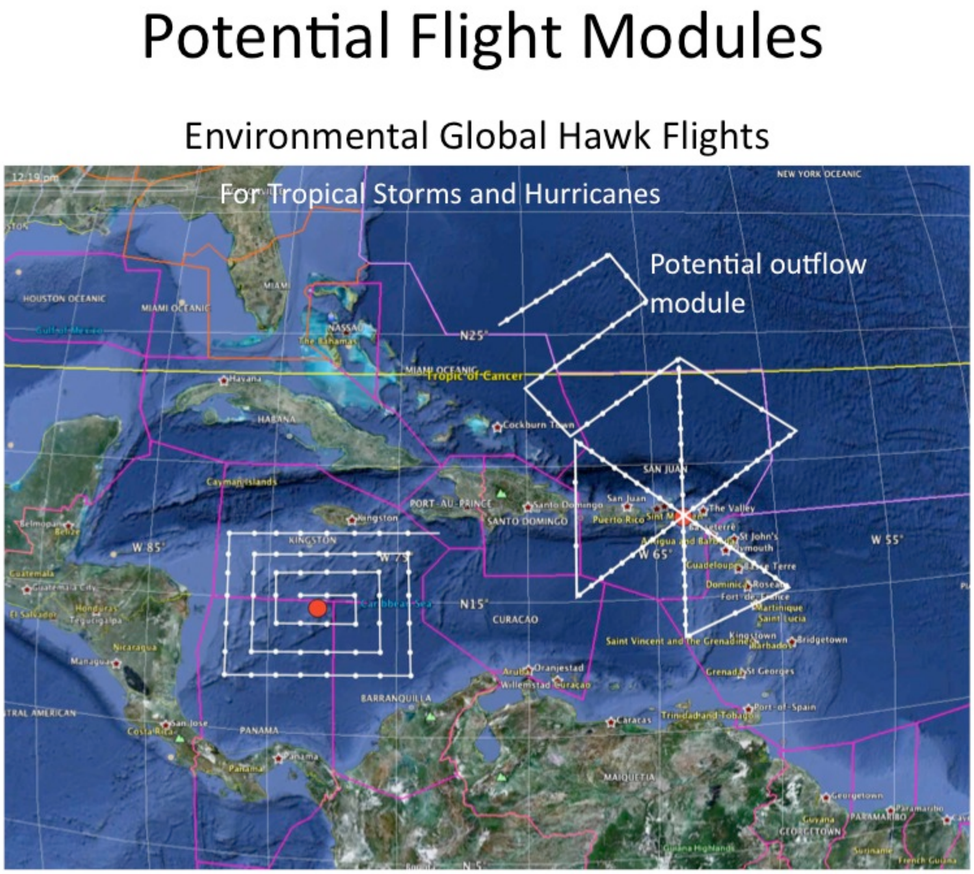


Figure 9-7. Sample square-spiral (in West Caribbean) and outflow module (in West Atlantic) flight patterns for GH's over two developing TC's in the Gulf of Mexico.

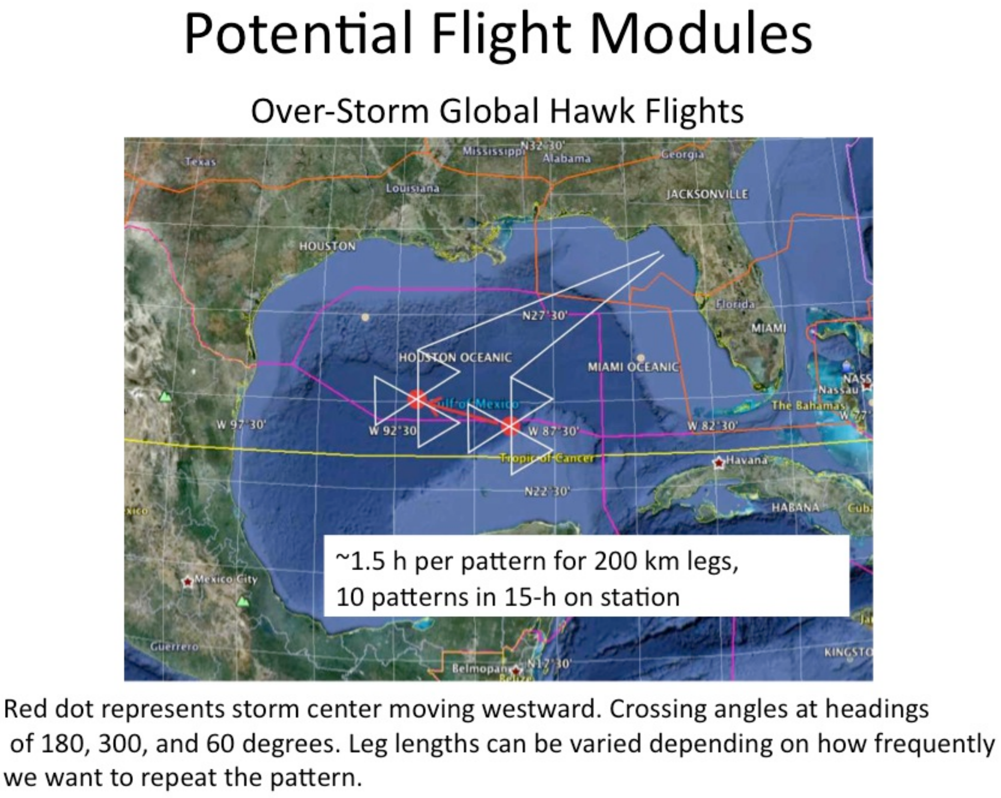
Tropical Cyclogenesis Experiment

Principal Investigator(s): Robert Rogers,Paul Reasor, and Wallace Hogsett (NHC)

Objective: To sample the wind, temperature, and moisture fields within and around a tropical disturbance that has the potential to develop into a tropical depression.

What to Target: A tropical depression or tropical storm (convection likely to be active at time of takeoff).

When to Target: During tropical depression stage, or if the tropical storm is in the early stage of its development.



Potential Flight Modules

Over-Storm Global Hawk Flights

~1.5 h per pattern for 200 km legs,
10 patterns in 15-h on station

Red dot represents storm center moving westward. Crossing angles at headings of 180, 300, and 60 degrees. Leg lengths can be varied depending on how frequently we want to repeat the pattern.

Figure 9-8. Sample figure-4 flight pattern for GH over a developing TC in the Gulf of Mexico.