9. East Pacific Easterly Wave Genesis Experiment

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Links to IFEX Goals:
Goal 1: Collect observations that span the TC life cycle in a variety of environments for model initialization and evaluation;
Goal 3: Improve understanding of the physical processes important in intensity change for a TC at all stages of its lifecycle.

Significance & Background:
Many studies have hypothesized that African easterly waves (EWs) serve as seed disturbances for East Pacific tropical cyclones (TCs) (e.g., Avila and Pasch 1992). However, it is often difficult to track African EWs crossing Central America and entering the East Pacific basin. In addition, African EWs may not be necessary to initiate EWs in the East Pacific. Several mechanisms for the in situ generation of EWs in the East Pacific have been proposed: 1) breakdown of the inter-tropical convergence zone (Ferriera and Schubert 1997), 2) barotropically unstable gap jets (Mozer and Zehnder 1996), 3) inertial instabilities from cross-equatorial pressure gradients (Toma and Webster 2010), 4) growth of vorticity noise by barotropic conversion in favorable basic states (Maloney and Hartmann 2001, Hartmann and Maloney 2001), and 5) upscale vorticity organization from diurnal convection in the Panama Bight (Rydbeck et al. 2016). This last mechanism for EW generation, proposed by Rydbeck et al. (2016), is the focus of this experiment.

East Pacific EW initiation can occur near the coasts of Panama and Colombia, with little or no preceding signal propagating from the Atlantic Ocean (Rydbeck and Maloney 2014). The Panama Bight has the highest occurrence of organized deep convection on the planet based on the NOAA Highly Reflective Cloud dataset (Kilonsky and Ramage 1976). Accordingly, mesoscale convective systems (and often mesoscale convective complexes) are initiated diurnally and propagate westward in boreal summer (Mapes et al. 2003). Previous studies have removed topography near the Panama Bight to demonstrate its vitality to the formation of convection in this region (e.g., Mapes et al. 2003, Rydbeck et al. 2016). Without the strong diurnal variability in Panama Bight convection, EW vorticity variance decreased by an order of magnitude in the Weather Research and Forecasting (WRF) model (Fig. 9-1).

Mesoscale convective systems in the Panama Bight are hypothesized to contribute to the initiation and intensification of EWs in the East Pacific through a process of upscale vorticity organization. When serial mesoscale convective systems are generated in the Panama Bight, precipitating regions are associated with positive vorticity anomalies and dry regions are associated with negative vorticity anomalies. In the middle troposphere, vertical stretching has been shown to increase the positive vorticity and decrease the negative vorticity in the region. Over successive mesoscale convective systems, the pattern of preferentially aggregating positive vorticity and dispersing negative vorticity in the vicinity of the Panama Bight leads to the development of long-lived cyclonic vorticity at mid levels that serves as the seed for an EW. These seeds are often referred to as “invests” in the hurricane forecast community.

In the very active 2015 East Pacific hurricane season, the Global Forecast System (GFS) under-predicted TC genesis in 120 h forecasts. This experiment aims to investigate a mechanism (i.e., convection in the Panama Bight) by which EWs form and from which TCs may develop in the East Pacific. A better representation of convection in the Panama Bight may improve EW initiation and growth in dynamical models, such as the GFS, thereby providing more realistic seed disturbances for TC genesis forecasts.

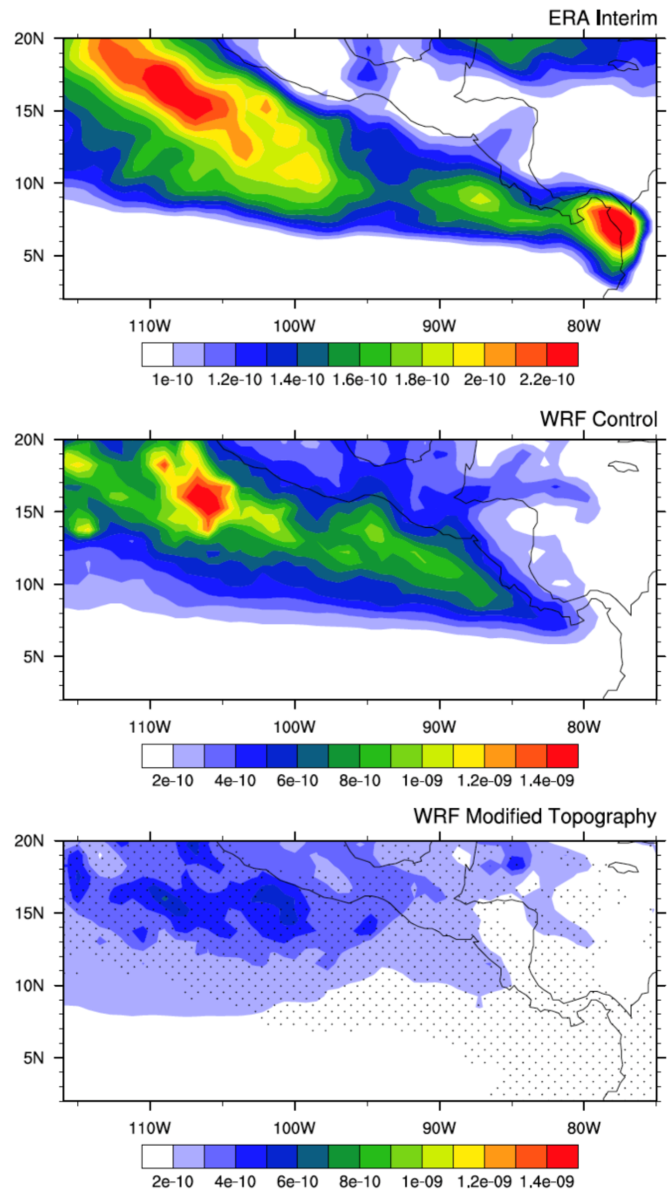

Figure 9-1. *2.5 – 12 day bandpass filtered 550-hPa relative vorticity variance (s-2, color contours) is shown for ERA-Interim (top), WRF control (middle), and WRF modified topography (bottom) for May-Nov. of 2000-2009. Figure from Rydbeck et al. (2016).*

Objectives: (List form)

- Collect NOAA G-IV Doppler radar, GPS dropwindsondes and flight level data in the Panama Bight.
- Document the dynamic and thermodynamic structure and evolution of diurnal convection, especially focusing on the aggregation of convection and vorticity.
- Differentiate between dynamic and thermodynamic structures that lead to TCs, invests and non-developers.

Hypotheses: (List form)

- East Pacific EWs can develop in situ near the Panama Bight without a pre-existing disturbance from the Atlantic Ocean.
- Panama Bight convection can reinvigorate a pre-existing disturbance that crosses into the East Pacific Ocean from the Atlantic Ocean.
- Westward propagating diurnal convection originating near the Panama Bight grows upscale via vertical vorticity stretching.

OSSE Evaluation:
Time and resource permitting, an OSSE will be performed to determine optimal flight patterns in order to maximize the impact of these observations on the GFS and HWRF systems.

Modeling Evaluation Component:
The data collected through this experiment will be used to evaluate biases in dynamical models, (e.g., GFS, HWRF). In 2015, the GFS under-predicted TC genesis in the East Pacific for 120 h forecasts. As demonstrated by earlier studies, the misrepresentation of convection (both timing and intensity) in the Panama Bight could have negative implications for EW initiation in the East Pacific. It is not clear if Panama Bight convection and its multiscale interactions are well represented in these dynamical models. Further, the upscale growth of vorticity anomalies (particularly through vertical vorticity stretching) associated with Panama Bight convection appears to be important for EW initiation. It is not clear how well dynamical models capture the growth of vorticity anomalies within mesoscale convective features via vortex stretching. The HWRF system, with its convection-permitting high-resolution nests, may be especially insightful into the dynamical and thermodynamical evolution of convection in the Panama Bight. An experimental uniform 3 km version of HWRF could be used to test the importance of horizontal grid spacing on convection and vorticity tendency biases in the Panama Bight.

Mission Description:
This is a **single-plane**, **multi-option** experiment. The target of this experiment is a developing East Pacific easterly wave, especially in the Panama Bight region. Priority will be given to disturbances that the National Hurricane Center (NHC) identifies as having a chance for development in the next 120 h. However, due to the typically disorganized state of convection in the Panama Bight, candidate disturbances may be identified via model forecasts and/or observations of an Atlantic Ocean EW about to propagate into the East Pacific. The NOAA G-IV is the only aircraft that will be employed for this experiment. NOAA G-IV flights that depart from Tapachula, Mexico will allow for the most on-station time in the Panama Bight. However, the Panama Bight may also be sampled if the NOAA G-IV departs from St. Croix. The range rings for Tapachula and St. Croix are provided in Fig. 9-2. Tampa and Barbados remain options, but should be considered last resorts since neither offers more than 2 hours of on-station time in the Panama Bight. The Panama Bight and surrounding areas are out of range for the NOAA P-3, so this aircraft should not be considered for this experiment.

This experiment is broken up into three (3) modules. The approximate location of each module is shown in Fig. 9-2. At least one (1) module must be chosen for this experiment to run, with the option for two (2) modules depending on the scenario, flight time and departure point. The three (3) modules are as follows:

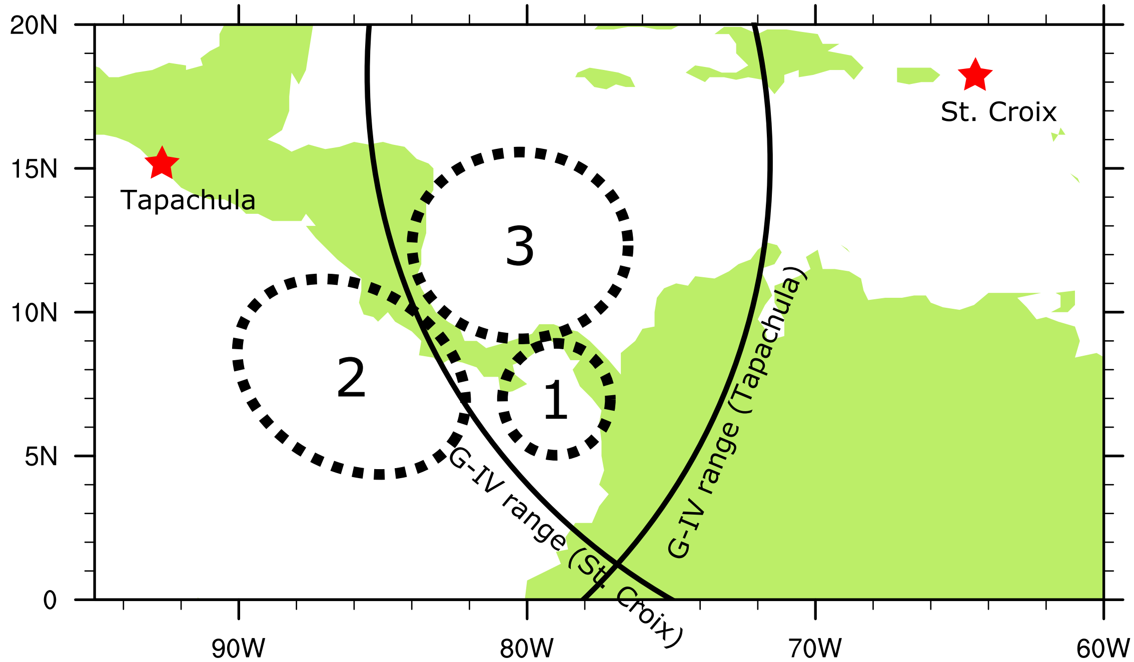

Figure 9-2. *Location of the three modules described in the East Pacific Easterly Wave Genesis Experiment. Tapachula, Mexico and St. Croix are shown along with NOAA G-IV range rings (assuming 2 hrs of on-station time).*

1) Panama Bight Convection Module

This module samples convection in the Panama Bight through a general survey of that region. The *Panama Bight Convection Module* is at the core of this experiment, which seeks to understand EW genesis or re-invigoration in the East Pacific. Convection is typically disorganized in the Panama Bight, which allows for a lot of flexibility in the flight plan to optimize sampling. This module will utilize tail Doppler radar, GPS dropwindsondes and flight level data to create an accurate picture of the dynamic and thermodynamic structure. A general survey pattern around the Panama Bight and the convection of interest is shown in Fig. 9-3. In general, GPS dropwindsondes should be deployed every 100 km along this general survey pattern, but this number can be adjusted based on dropwindsonde availability. Detours to circle/box around features of interest are encouraged, provided they can be done so safely. For example, the mesoscale convective system (MCS) depicted near 80.5°W would be a prime target for such a detour. GPS dropwindsondes should be deployed every 25-50 km, but this number can be adjusted based on dropwindsonde availability. This module can be combined with the *East Pacific Development Module* or the *Easterly Wave Transition Module* in order to maximize the data collected per flight. Note that, while all flight patterns below depict a smoothly-varying rounded pattern, in fact all efforts should be made to conduct turns with a series of straight and level segments, to minimize loss of radar data from aircraft banks.

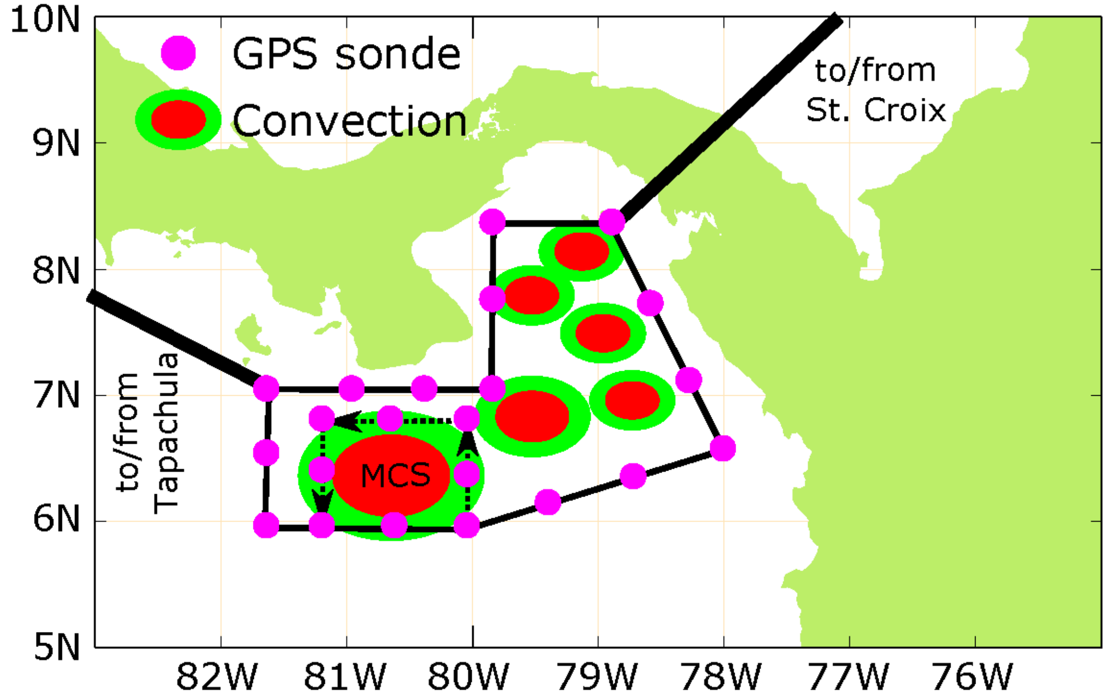

Figure 9-3. *The Panama Bight Convection Module.*

2) East Pacific Development Module

This module surveys an EW in the East Pacific (southeast of Tapachula, Mexico) that is showing signs of development. Ideally, this module will be useful to continue tracking a disturbance that originates and grows from the Panama Bight region. To maintain this connection in the analysis, candidate EWs should be located east of 90°W. This module is only available for flights departing from Tapachula. It is out of range for the NOAA G-IV from every other base. Rydbeck et al. (2016) found evidence that Panama Bight convection to the east of a developing EW is responsible for increasing vorticity on the backside of the EW and slowing the propagation speed of this disturbance. Therefore, the *East Pacific Development Module* pairs well with the *Panama Bight Convection Module*. These two modules may be completed in the same flight, in any order.

Two general flight pattern options exist for this module (Fig. 9-4). The precise flight plan will depend on the situation. If the disturbance is still disorganized (very likely), then a general survey pattern around the storm is recommended. However, if the disturbance is organized, a figure-four flight pattern is recommended, anchored to the estimated center location. Please note that if no discernable disturbance can be identified, this module should be skipped in order to maximize on-station time in the Panama Bight. This module will utilize tail Doppler radar, GPS dropwindsondes and flight level data to create an accurate picture of the dynamic and thermodynamic structure of the developing disturbance. For the figure-4 pattern, dropsondes should be released at the turn points, midpoints, and one center pass. For the survey flight path, GPS dropwindsondes should be deployed every 100 km, but this number may be changed based on availability.

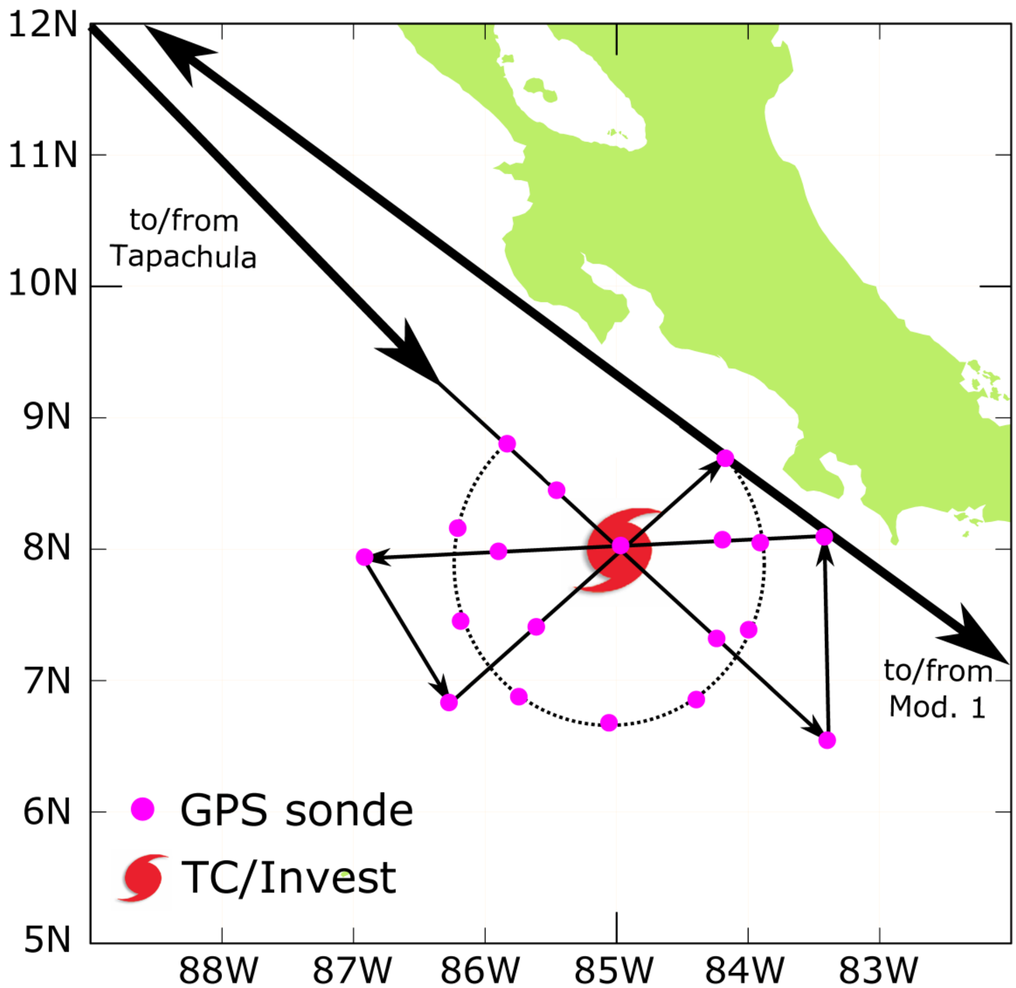

Figure 9-4. *The East Pacific Development Module.*

3) Easterly Wave Transition Module

This module surveys an EW that is transitioning from the Atlantic basin to the East Pacific basin. While recent work has highlighted the in situ generation of EWs in the East Pacific, many studies have shown evidence supporting the propagation of robust EWs from the Atlantic into the East Pacific. Convection in the Panama Bight may be important for the maintenance, or re-invigoration, of these EWs as they cross Central America. EWs that are north of 15°N should not be considered for this module since these disturbances are too far from the Panama Bight and are less likely to propagate into the East Pacific. In addition, candidate EWs should be located at and to the west of 78°W (longitude of Panama Bight). A broad survey around the EW while in the extreme western Caribbean Sea is recommended (Fig. 9-5). GPS dropwindsondes should be deployed every 100 km, but this number may be changed based on availability. Combination with the *Panama Bight Convection Module* is encouraged.

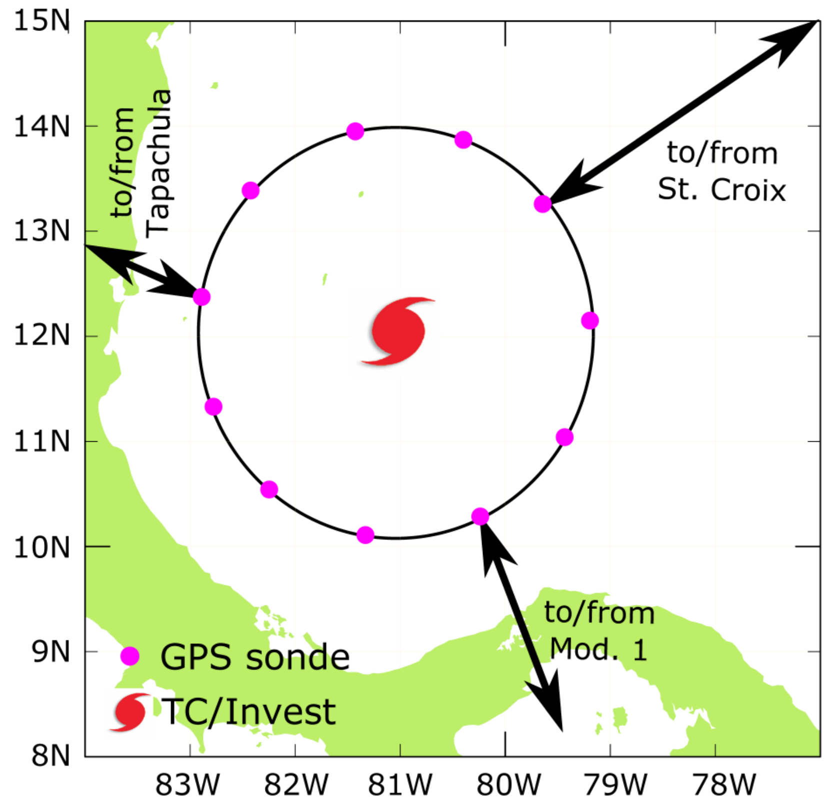

Figure 9-5. *The Easterly Wave Transition Module.*

Analysis Strategy:

The analysis strategy is the same for all three modules. Winds and vorticity are the most important fields to retrieve to compare with previous work on the importance of Panama Bight convection. Tail Doppler radar will be especially useful to reconstruct a three-dimensional wind field structure for convective cells, which will be vital in the calculation of vertical vorticity stretching. Vertical vorticity stretching has been hypothesized to be key for the upscale growth of vorticity in the Panama Bight region. Thermodynamic fields, such as temperature and moisture, will be leveraged to identify thresholds necessary for convection in the Panama Bight as well as back out vertical profiles of Q1, the apparent heat source, and Q2, the apparent moisture sink. In a regional model and global reanalysis these profiles have been shown to evolve over time as mesoscale convective systems and EWs intensify in the Panama Bight region (Rydbeck et al. 2016). In a regional model, Q1 evolves into a robust stratiform heating profile consistent with the local generation of mid level vorticity, a result we hope to validate with this experiment. In addition, biases related to the dynamic and thermodynamic structure of Panama Bight convection will be identified in the GFS and other dynamical models.

Coordination with Supplemental Aircraft:
NOAA is planning to conduct the SHOUT field campaign during the 2016 hurricane season. The SHOUT campaign will utilize one unmanned Global Hawk (GH) aircraft, flying at approximately 55-60,000 ft. altitude with mission durations of ~24 h (Fig. 9-6). The GH will be equipped with a GPS dropwindsonde system capable of deploying 88 dropwindsondes per mission, the JPL HAMSR microwave sounder for analyzing 3-D distributions of temperature (e.g. the TC warm core), water vapor, and cloud liquid water, and the NASA HIWRAP dual frequency Doppler radar for observing 3-D winds, ocean vector winds, and precipitation. The primary science goals of SHOUT include: i) improving model forecasts of TC track and intensity by designing optimal GPS dropwindsonde sampling strategies for the Global Hawk using a real-time ensemble data assimilation and forecasting system; and ii) gaining a better understanding of both the inner-core and environmental processes that are important to TC intensity change.

When possible, it will be desirable to fly patterns with the NOAA P-3 and/or G-IV aircraft that are coordinated with the GH. For the NOAA G-IV, "coordinated" means optimizing far field and AEW sampling either concurrently or on alternating days (to attain nearly continuous 2-plane coverage of both the EW and peripheral environment). The details of these coordinated missions will be handled on a case-by-case basis.

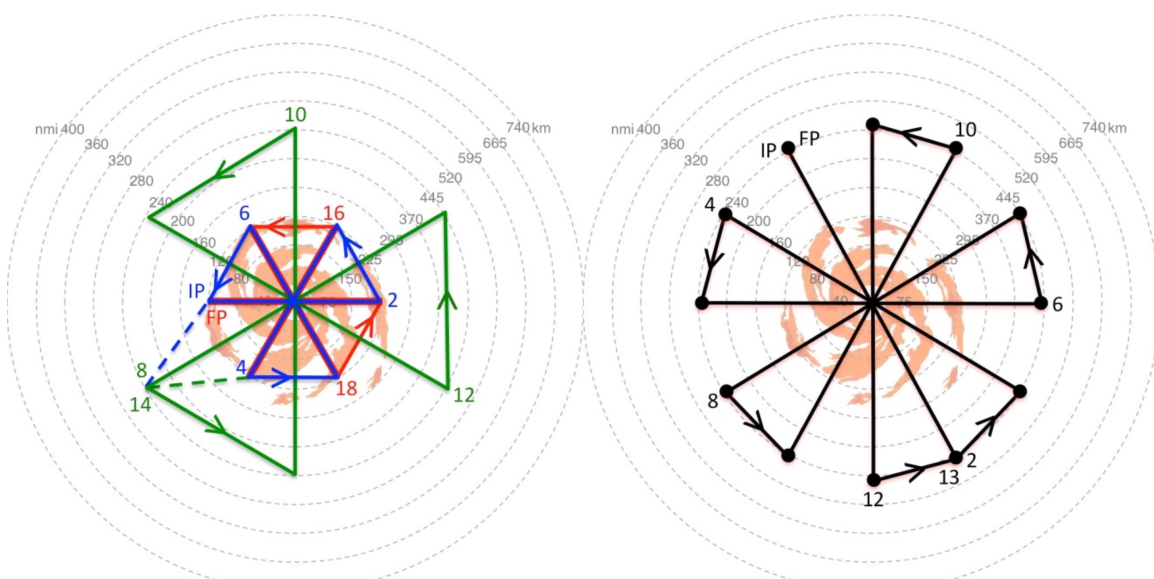

***Figure 9-6**. Sample GH flight patterns for the 2016 NOAA SHOUT field campaign. (Left) sequence of small-large-small butterflies. The small butterfly patterns have 120 nm (220 km) radial legs and take ~3-hr to complete while the large butterfly pattern has 240 nm (450 km) legs and takes ~6.5-hr to complete. (Right) rotated butterfly pattern with 30 degree rotated radials that are 240 nm (450 km) in length from the storm center. Both GH patterns would be flown in a storm relative framework.*

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