10. Rapid Intensification Experiment (RAPX)

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Links to 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 some improvements in operational tropical cyclone intensity forecasting have been made in recent years (DeMaria et al. 2014), predicting changes in tropical cyclone intensity (as defined by the 1-min. maximum sustained wind) remains problematic. In particular, the operational prediction of rapid intensification (RI) has proven to be especially difficult (Kaplan et al. 2010) and given the significant impact of such episodes, has prompted the Tropical Prediction Center/National Hurricane Center (TPC/NHC) (Rappaport 2012) to declare it as its top forecast priority. The difficulty of forecasting RI stems from a general lack of understanding of the physical mechanisms that are responsible for these rare events. Generally speaking, researchers have attributed RI to a combination of inner-core, oceanic, and large-scale processes.

To date, statistically-based prediction schemes such as the SHIPS rapid intensification index (SHIPS-RII) (Kaplan et al. 2010) and the more recently developed Bayesian and logistic regression RI models (Rozoff and Kossin 2011) have generally been shown to provide the most skillful objective RI guidance (Kaplan et al. 2015). The aforementioned models employ predictors derived from large-scale fields and GOES infrared satellite imagery. These models include such predictors as the environmental vertical wind shear and moisture, the departure of the vortex's present intensity from its empirical maximum potential and the symmetry of the inner-core convection around the storm center as deduced utilizing GOES infrared imagery. Kaplan et al. (2015) showed that the statistical models, such as the SHIPS-RII, are capable of explaining roughly 20% of the skill of Atlantic basin RI forecasts at a lead-time of 24-h. Thus, the remaining 80% of the skill not explained by the statistical models is assumed to be attributable either to processes not explicitly accounted for by those models or by limitations in the predictability of RI events. Rogers et al. (2013b; 2015) used airborne Doppler measurements to identify several characteristics of the inner-core structure of tropical cyclones that were associated with intensification, though many questions were raised from this work related to the mechanisms responsible for the formation of these structures. In particular, the interaction of the vortex with vertical shear, the role of vortex tilt and alignment, and the distribution, structure, and evolution of deep convection (and other modes of precipitation) prior to and during RI are all outstanding questions. The goal of this experiment is to collect datasets that can be used both to initialize 3-D numerical models and to improve our understanding of RI processes across multiple scales, with the overarching goal of improving our ability to predict the timing and magnitude of RI events.

Objective:

To employ both NOAA P-3 and G-IV aircraft to collect oceanic, kinematic, and thermodynamic observations both within the inner-core (i.e., radius < 220 km) and in the surrounding large-scale environment (i.e., 220 km < radius < 440 km) for systems that have been identified as having the potential to undergo RI within ~96 h. Both the probabilistic statistical RI guidance (i.e., SHIPS-RII, Bayesian, logistic regression) and numerical models will be used to assist with selection of candidate systems for the short-term time periods (lead times ≤ 48 h) while both the statistical and numerical models will be used at the longer lead times (i.e., beyond 48 h). The datasets collected from this experiment will aid in the quantification of the current capabilities of the operational coupled model forecast system to adequately distinguish the environmental, vortex, and convective-scale structures of tropical cyclones that undergo RI from those that do not.

Hypotheses:

- By gathering observations that span spatial scales from 10s to 100s of kilometers it is possible to improve our understanding of the atmospheric and oceanic conditions that precede RI, particularly within the less observed inner-core region.

- Characteristics of the tropical cyclone inner core, both on the vortex- and convective-scale, contribute a non-negligible amount to the predictability of RI.
- The aforementioned multi-scale RAPX data sets can be used both to initialize and evaluate numerical model forecasts made for episodes of RI and successful completion of these tasks will lead to improved numerical and statistical model predictions of RI.

Model Evaluation Component: Recent analysis of global and airborne Doppler data have shown that statistically significant differences exist in the environmental and the inner-core structures of steady-state and rapidly intensifying TCs. In addition to the differences in the large-scale variables utilized by the statistical RI models described above, variations in such structures as the inner- and outer-core vorticity field, inflow depth and strength, and number, radial, and azimuthal distribution of deep convection have been found to exist for RI and non-RI TCs. Since the data collected as a part of this experiment will span scales ranging from the environmental down to the convective and PBL scale, it should provide a means of evaluating the various features of the operational modeling system, including the sufficiency (or lack thereof) of the horizontal resolution, and the microphysical and planetary boundary layer parameterization schemes.

Mission Description:

Missions will be targeted for systems that have a reasonable chance of undergoing RI, based on the guidance indicated above. When possible (i.e., subject to range, timing, and other logistical constraints), missions will begin as much as 24 h prior to the expected onset of RI, even if the storm is still only a tropical depression or storm, to capture the structure during the time leading up to RI onset. Ideally missions will continue every 12 h, as long as feasible. The P-3 aircraft will dispense AXBTs and GPS dropsondes and collect Doppler radar data while flying a rotating figure-4 pattern (see sample pattern shown in Fig. 1) in the inner-core with leg lengths of ~90-180 km at the maximum safe altitude (~8k-12k feet) for avoiding graupel. The AXBTs and GPS dropsondes should be dispensed on each leg with a spacing of ~30-40 km to provide adequate coverage for deducing the radial variations in kinematic and thermodynamic storm properties. Particular efforts should be made to release expendables outside the flight-level radius of maximum winds (RMW); i.e., between ~1xRMW and 3xRMW. The desired AXBT/GPS dropsonde deployment strategy is for both an AXBT and GPS dropsonde to be dispensed in tandem at both the endpoints and midpoint of each leg of the figure-4 pattern so that a total of 12 AXBT/GPS pairs are dropped during the course of each completed figure-4 leg (pattern) as shown in Fig. 10-1. Additional dropsondes (no AXBTs) can be dropped at the discretion of the LPS to increase the radial and/or azimuthal coverage, particularly outside the RMW. The P-3 may also fly a Convective Burst Module (similar to that flown for the tropical cyclone genesis experiment) or an Arc Cloud Module if the opportunity to conduct such flight patterns presents itself.

The G-IV should fly the environmental pattern shown in Fig. 10-2 at an altitude of ~41-45 K ft. dispensing dropsondes at radii of 220, 330, and 440 km to measure the thermodynamic and kinematic fields in the near storm environment. These particularly radii were chosen since collecting data in this region is crucial for computing the vertical shear and upper-level divergence, both of which have been shown to be strongly correlated with RI. The radii of the innermost ring of G-IV drops shown in Fig. 10-2 can be adjusted outward if necessitated by safety considerations. However, the radii of the other rings of drops should then also be adjusted to maintain the specified 1-deg spacing. Depending on the time of day, aircraft duration limitations, and safety considerations, the lengths of the G-IV inner (outer) points could be shortened (extended) to ~200 km (~500 km) if an opportunity to sample a diurnal pulse "IR cool ring" presents itself (see TC Diurnal Cycle Experiment).

As noted above, this experiment requires that both the P-3 and G-IV be utilized. In addition, it is highly desirable that the P-3 aircraft fly a rotating figure-4 pattern (see Fig. 10-1) in the inner-core while the G-IV simultaneously flies the environmental surveillance pattern shown in Fig. 2a every 12 h. Although this mission can still be conducted if the G-IV aircraft flies a synoptic surveillance pattern instead of the one depicted in Fig. 10-2a, such a flight pattern should only be flown in the event that the G-IV has been tasked by the NHC to conduct an operational synoptic surveillance mission and thus would otherwise be unavailable for use in research missions. Furthermore, if either the P-3 or G-IV aircraft cannot fly every 12 h the experiment can still be conducted provided that the gap between missions for any one of the two aircraft does not exceed 24 h. Alternatively, an octagonal survey pattern like that depicted in Fig. 10-2b can also be flown by the G-IV aircraft. Such a pattern will allow Doppler radar measurements to be effectively collected from the G-IV, and would be particularly desirable if the P-3 were not available.

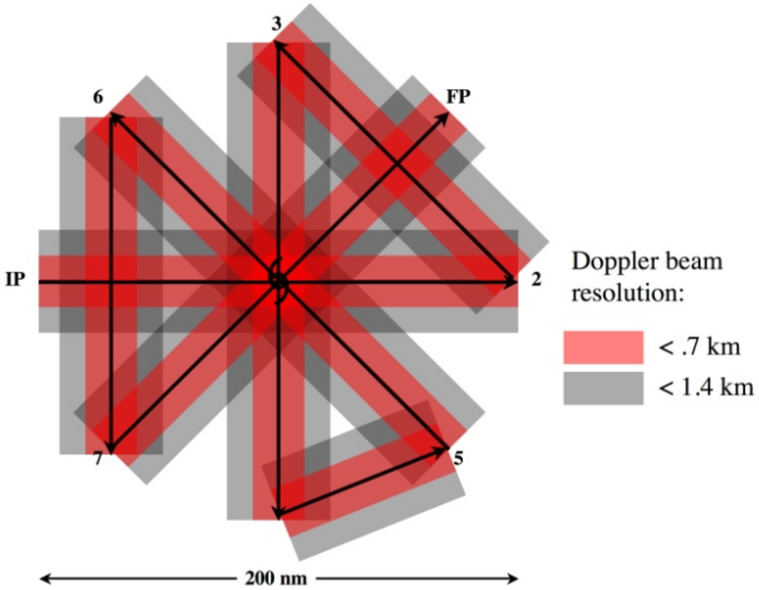

Figure 10-1. *Sample rotated figure-4 flight pattern for RAPX mission. The red shading denotes locations where vertical spacing of Doppler beam < 0.7 km, grey shading where vertical spacing < 1.4 km. GPS dropsondes should be released at all turn points (past the turn after the aircraft has leveled), at midpoints of inbound/outbound legs, and at center point between IP/2 and 5/6. An additional dropsonde should be released between the midpoint and turn points for each radial pass. If available, release AXBT's coincident with dropsondes at turn points, midpoints, and center points. Note that the above in-storm P-3 flight pattern requires about 3-4 hours to complete.*

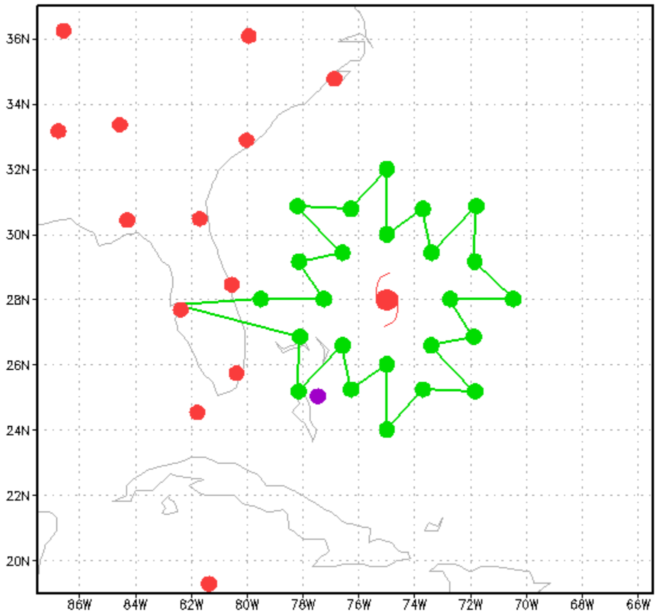

Figure 10-2a. *A sample G-IV flight pattern for the RAPX mission. The green dots denote the desired dropsonde locations at 220, 330, and 440 km radius from the storm center. Note that the end oints of each leg can be rounded slightly as required for aircraft flight considerations. The flight pattern shown in Fig. 2a (excluding ferry time to and from the storm) requires about 6 hours to complete.*

It is worth noting that there exists the potential to perform the RAPX experiment in the eastern North Pacific basin while operating out of Mexico during the upcoming 2016 Hurricane Season. Finally, when possible this experiment may also make use of the NASA Global Hawk aircraft that will be employed during the upcoming 2016 Hurricane season as part of the SHOUT program.

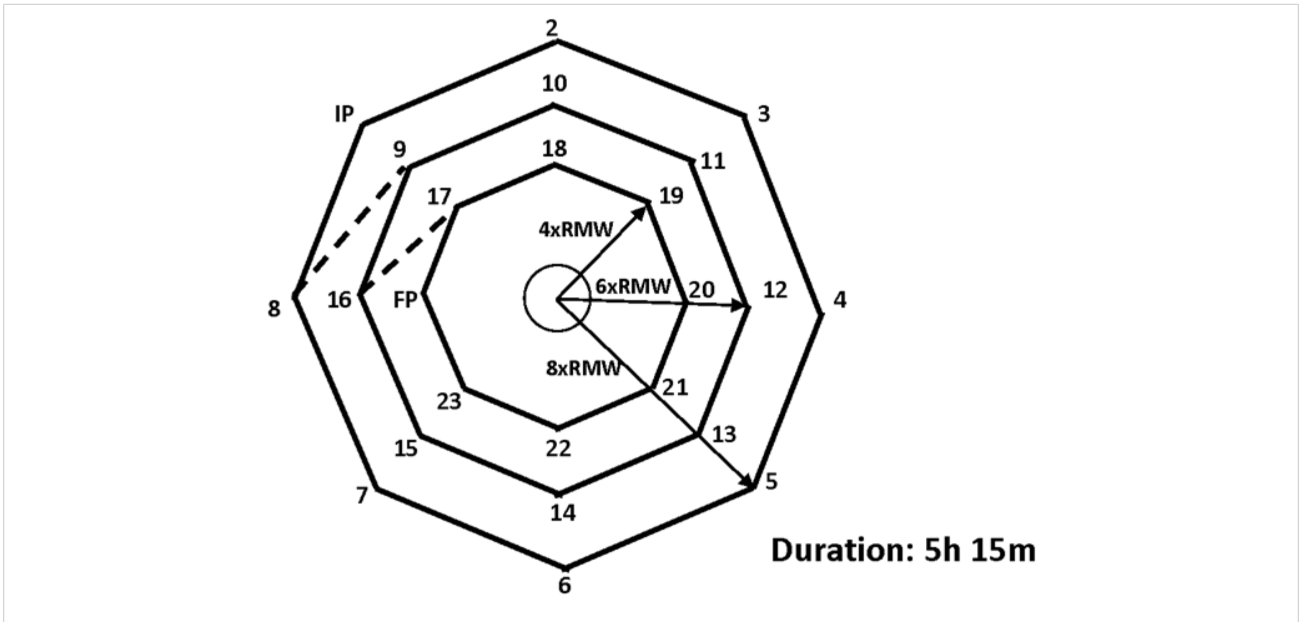

Figure 10-2b: *G-IV outer-core survey pattern.*

- Altitude: 40-45 kft
- Expendables: Deploy dropsondes at all turn points. No more than 24 GPS drops needed.
- Pattern: The pattern is flown with respect to the surface storm center. Three concentric octagons are flown clockwise at decreasing radii of 8xRMW, 6xRMW, and 4xRMW, where RMW is the estimated radius of maximum azimuthal-mean tangential wind (estimated from flight-level observations). For example, if RMW=18 nm, the maximum radial extent of the pattern is 144 nm. Dashed lines show transitions between rings.
- Instrumentation: Set airborne Doppler radar to scan F/AST on all legs.

Analysis Strategy

This experiment seeks to perform a multi-scale analysis of the conditions both before and during RI. Specifically, we will use GFS, GPS dropsonde, and ocean buoy observations to analyze the changes in energy transfer at the ocean-atmosphere interface during the time period of the experiment. Also, changes in the inner-core (i.e., radius <220 km) kinematic and thermodynamic structure will be examined using NOAA P-3 Doppler radar, flight-level, and GPS dropsonde data. Inner-core analyses will include an analysis of the symmetric and asymmetric vortex structure, vortex tilt, and inner-core vertical shear derived from airborne Doppler and dropsonde data and statistics of vertical velocity, vorticity, and reflectivity from airborne Doppler. Finally, an analysis of the near-storm large-scale environment (i.e., radius < 440 km) will be conducted using the high-resolution GFS analyses that contain the assimilated GPS dropsonde data deployed from NOAA G-IV aircraft. This near storm sampling effort will aid in the evaluation of many of the predictors being used in the current operational SHIPS RII including the vertical shear and a new predictor that employs microwave-derived total precipitable water imagery to detect dry air in the upshear TC environment. The overarching hypothesis of this analysis strategy is that by performing similar analyses for multiple RAPX data sets collected during both RI and non-RI events it will be possible to determine the conditions that are triggers for RI and to evaluate numerical model performance during such events.

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. The GH will be equipped with a GPS dropsonde system capable of deploying 88 dropsondes 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 G-IV aircraft that are coordinated with the GH. For the NOAA P-3, “coordinated” means flying radial penetrations where the P-3 when the GH are vertically-stacked for at least a portion of the flight leg, preferably when the aircraft are approaching the center of the TC. 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 planned figure-4/butterfly/rotating figure-4 patterns as indicated in Fig. 10-1. The GH can fly patterns that are similar in geometry to the NOAA P-3 patterns (see Fig. 10-3). To achieve coordination the P-3 would align its legs such that the GH will be stacked with the P-3. Given the relatively long turn around of the NASA GH (~24-hr), the NOAA P-3 could also coordinate with the NOAA G-IV and GH on alternating days to attain nearly continuous 2-plane coverage of both the TC inner core and peripheral environment. The details of these coordinated missions would be handled on a case-by-case basis.

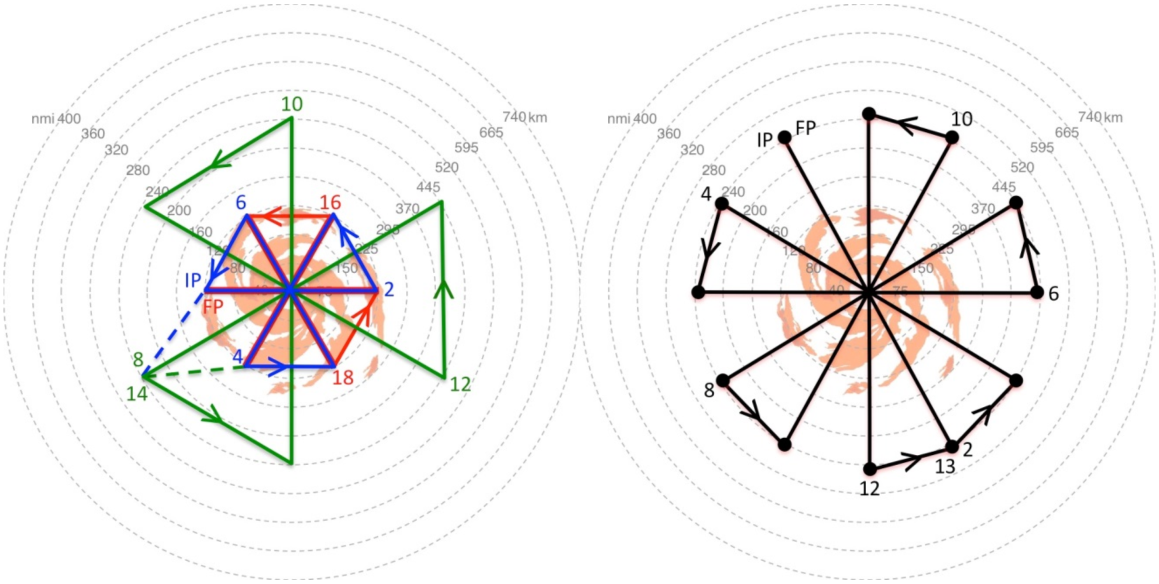

Figure10-3. *Sample GH flight patterns for the 2016 NOAA SHOUT field campaign. (Left) sequence of small-large-small butterflies. The small butterfly patterns have 120 nm (220 km) radial legs and take ~3-hr to complete while the large butterfly pattern has 240 nm (450 km) legs and takes ~6.5-hr to complete. (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.*