3. Optimizing Observations to Better Evaluate and Improve NOAA's Hurricane Weather Research and Forecasting Operational Model

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Primary IFEX Goal:

1 – Collect observations that span the tropical cyclone (TC) lifecycle in a variety of environments and for model initialization and evaluation.

3 - Improve understanding of the physical processes important in intensity change for a TC at all stages of its lifecycle

Overarching Objective:

Improve NOAA's Hurricane Weather Research and Forecasting (HWRF) model performance through a systematic evaluation process, whereby model biases are documented, understood, and ultimately eliminated by implementing accurate observation-based physical parameterizations.

Statement of the problem: Recent experiments related to the use of in-situ observations for improved PBL representation in the HWRF system, increased frequency of physics calls and the subsequent steep-step improvements to structure and intensity predictions illustrate the importance of improving the physical representation of hurricane processes in the modeling system. Additional model comparisons with in-situ observations show that the hurricane near-surface thermodynamic environment in NOAA's HWRF operational model is generally too warm and too moist. Recent comparisons of the coupled modeling system with observations also suggest that the existing ocean used in HWRF (POM) has a tendency to under-cool. Biases such as these impact how surface fluxes are generated in the model and, as a result, can significantly (and adversely) affect hurricane structure, intensity, as well as the intensity change process.

What to target: This experiment is designed to obtain high-resolution kinematic, thermodynamic and microphysical measurements in convectively active areas of the hurricane environment (both rain-band and inner core). In addition, this experiment will capture areas of strong downdraft activity so as to better assess highly transient, yet critically important physical processes responsible for modifying hurricane boundary layer thermodynamic structure. Finally, this effort will also document the ocean environment from the pre-storm quiescent stage through storm passage with the goal of quantifying ocean response in a storm-centric framework.

Mission Description The mission as described below consists of two components: an atmospheric and an oceanic component.

Atmospheric component

The ideal experiment consists of coordinated three-plane missions designed to observe several mechanisms responsible for modulating convective activity, hurricane structure and storm intensity change, including:

- Air-sea energy exchange and boundary layer processes
- Convection (storm scale and surrounding environment)
- Dynamic/thermodynamic processes (storm scale and surrounding environment)
- Cloud microphysics

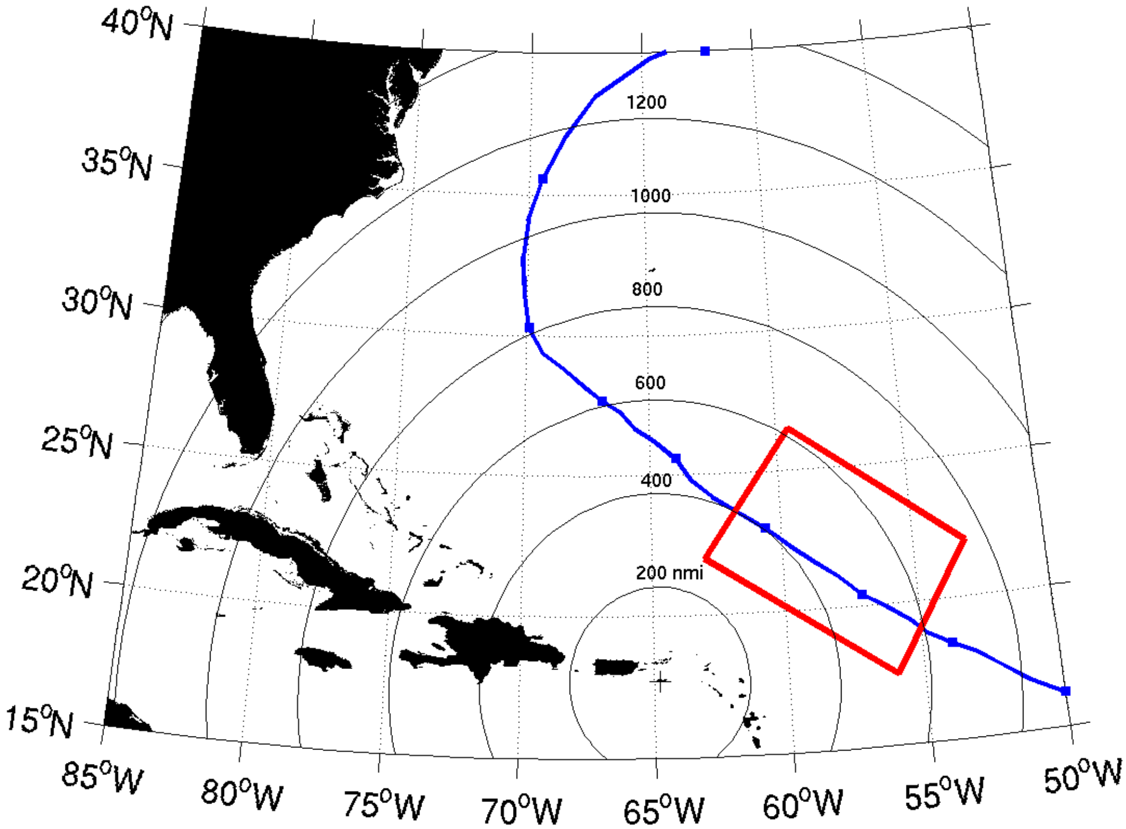

Figure 3-1: Storm track (blue), and observation region (red box), optimally suited for multi-aircraft experiment. Range rings are 200 nmi relative to forward operating base at STX (TISX). Track marks are spaced every 24 hrs.

This multi-aircraft experiment is ideally suited to geographical locales, which limit conflict with other operational requirements, for example, at a forward/eastward-deployed base targeting a storm not imminently threating the U.S. coastline. An optimal geographical situation is shown in Fig. 3-1. It is also worth noting that without such a deployment plan systems not considered to be an immediate threat to make US landfall would likely not be sampled (e.g. Katia 2011).

Each participating aircraft is assigned a "process of responsibility", whereby the pattern is designed to address specific phenomena and/or processes. Conceptually, this experiment consists of a collection of coordinated modules included in previous years' Field Program plans. It should also be noted that this experiment will be targeting mature hurricane systems and relies on a 24h cycle of observations (centered roughly on 18Z) with simultaneous utilization of 3 NOAA aircraft (N42RF, N43RF, and N49RF). While several "modular options" exist for this particular experiment, it is important to emphasize that the overall goal is to adequately capture multi-scale interactions within the tropical cyclone environment (i.e. environment/vortex/convective-scale). By doing so, it will be much easier to conduct "budget-oriented" analyses required to accurately evaluate model physical fields and processes.

Capturing structure associated with outer TC environment will be primarily the responsibility of the NOAA GIV aircraft (N49RF). One of the preferred patterns that will be employed is the "starfish" configuration already outlined in several existing HFP experiments (most notably in the RI experiment). Another possible pattern that could be utilized is the circumnavigation flight plan currently described in the shear experiment. In either case, the intention for this experiment would be to fly the GIV simultaneously with both P-3 aircraft.

One of the NOAA P-3 aircraft will be responsible for capturing storm scale environment (wave number 0/1). Here, the in-storm plan is likely to use a rotating Figure-4 flight pattern (similar to what is currently used for TDR missions). If circumstances dictate, a modified butterfly pattern could be used instead. The exact details of the pattern (e.g. Figure 4, butterfly, specific leg lengths, etc.) will be determined on a flight-by-flight basis.

The second P-3 (likely N43RF) would be tasked to sample pre-determined, high-value areas of interest within specified region(s) of the storm. For situations where only one P-3 is available, a portion of that P-3's mission would consist of a vortex survey pattern (e.g., butterfly, Figure-4, etc.), while the remainder of the mission would involve the more targeted module mentioned above. The amount of time conducting the survey portion of the pattern would be designed to provide at least some time (e.g., 1 h) to conduct the more targeted sampling pattern.

A visual depiction of the verbal description above follows (again, subject to the caveat of two P-3's being available as mentioned in the previous paragraph; otherwise the one P-3 does a portion of each of these patterns):

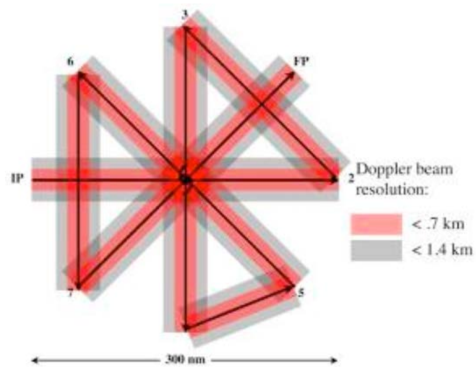

Figure 3-2. One NOAA P3: Captures the core, storm scale circulation (e.g. Current TDR mission profiles)

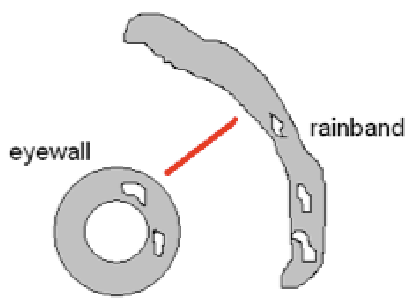

Figure 3-3. 2nd NOAA P3: Responsible for sampling predetermined areas of interest outside the immediate TC high wind inner core (e.g. Entrainment flux module)

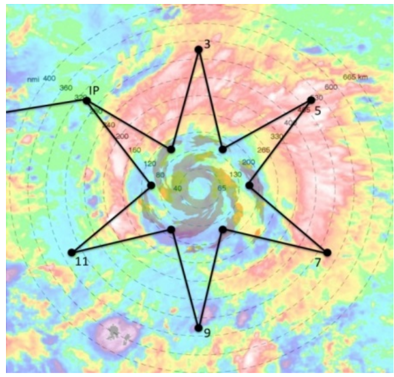

Figure 3-4. NOAA GIV: Primarily responsible for capturing the tropical cyclone's surrounding larger scale environment

As previously mentioned, the processes that will be targeted include air sea exchange, vertical/horizontal transport resulting from convective activity (including boundary layer entrainment and cloud microphysical processes), interactions with the surrounding environment, and ocean response. These are 3 high-priority research foci for this experiment:

a) Air-sea exchange: At the initiation of the observing period, the pre-storm, in-storm, and post-storm oceanic environment is sampled to estimate horizontal and vertical ocean structure which is forecasted to respond to TC forcing (sampling ideally begins 1-2 days prior to the storm's arrival). The observations consist of a field of ocean expendable probes (AXBT, AXCTD, AXCP), and possibly a line of surface drifting probes in coordination with the 53rd WRS. The pre-storm "field" is designed to extend over a significant area to capture a multi-day event. The Ocean component of this experiment (see below), the Small Unmanned Aircraft Vehicle Experiment (SUAVE), and the Hurricane Boundary Layer Inflow Module support the pre-storm element of the air-sea exchange focus.

As the TC advances across the previously-sampled region, a series of in-storm missions are executed to observe the storm's evolution. These missions may be carried out in conjunction with other planned experiments, however, one P-3 aircraft is generally assigned the responsibility of observing the overall storm structure, while the other P-3 has a more specific mission to target the localized convective impact (discussed later). The storm-scale P-3 ideally executes a rotated Figure-4 pattern, deploying GPS dropwindsondes and AXBTs in combination to estimated surface fluxes. The operational P-3 three-dimensional Doppler winds mission supports the in-storm element of the air-sea exchange focus. Finally, a post-storm survey mission will be conducted to look at ocean response. In anticipation of a coordinated surface drifter deployment, the post-storm ocean current and temperature responses can be observed by drifters for several days after passage. In the absence of drifters, a final, post-storm expendable profiler sampling mission will be required for coupled model evaluation purposes. The Ocean Response Experiment (1) supports the post-storm element of the air-sea exchange focus.

b) TC Inner Core Processes (R<~150 km): The convection-scale P-3 executes one or more experiments/modules to sample convective bursts, outer rain-band structure, boundary layer thermodynamic and kinematic fields, mid-level moisture, boundary layer top entrainment, and surface energy exchanges using a combination of flight-level data, LF radar, tail Doppler radar, W-band radar, Doppler Wind Lidar, GPS dropsondes, and low flying UAS. The Hurricane Boundary Layer Entrainment Flux Module (2), the Hurricane Boundary Layer Inflow Module (3), SUAVE (4), the Doppler Wind Lidar (DWL) Boundary-layer Module (8), Rapid Intensification Experiment (5), Microphysics-Aerosol/Cloud droplet measurement option (6), the Saharan Air Layer Experiment: arc cloud module (7), TC Diurnal Cycle Experiment (10), TC in Shear Experiment (11) and Convective Burst Module (12) support the TC Inner Core Processes focus of this experiment.

c) TC Environment Processes (R>~150 km): The 2nd P-3 and G-IV execute one or more experiments/modules to sample low-level advective transport of moisture from the environment, TC boundary-layer moisture, mid-level moisture, easterly jets and aerosols in the Saharan Air Layer, environmental conditions that promote rapid intensification, diurnal variations in cirrus canopy thermodynamics and outflow, and the impact of convectively driven downdrafts and outflow boundaries on TC structure and the TC boundary layer. In order to promote measurements of the impact of the environmental moisture and vertical wind shear on the storm, the G-IV aircraft is tasked with deploying GPS dropwindsondes between 200 and 400 km distance from the storm center. The general flight pattern consists of quasi-radial legs to and from the annulus limits around the storm. SUAVE (4), the Hurricane Boundary Layer Entrainment Flux Module (2), the Hurricane Boundary Layer Inflow Module (3), the Doppler Wind Lidar (DWL) Boundary-layer Module (8), Rapid Intensification Experiment (5), Microphysics-Aerosol/Cloud droplet measurement option (6), the Saharan Air Layer Experiment: arc cloud module (7), the Doppler Wind Lidar (DWL) SAL Module (9), the TC Diurnal Cycle Experiment (10), TC in Shear Experiment (11) and the Convective Burst Module (12) support the TC Environmental Processes focus of this experiment.

There are several research experiments/modules that support the air-sea interaction, TC Inner Core Processes, and TC Environment Processes foci of this overarching experiment. These experiments/modules include:

1) **Oceanic component of this experiment** (Uhlhorn, Lumpkin, Centurioni, Shay; see below for more complete description)
Goal: To observe and improve our understanding of the upper-ocean's response to near-surface wind forcing during TC passages. Specific objectives are to: 1) Quantify the influence of the underlying ocean on atmospheric boundary layer thermodynamics and ultimately TC intensity; and 2) Document the capabilities of the operational coupled model forecast system to accurately capture and represent these processes. Refer to the Oceanic component of this experiment below for additional details.
Model evaluation component: Capturing accurate estimates of ocean response to TC forcing is critically important in a coupled atmosphere-ocean modeling system. This module will help better quantify model performance as it relates to ocean model initialization, storm-scale upper ocean cooling and post storm, cool wake realization (which, in turn, could impact future tropical systems that traverse similar ocean environments).

2) **Hurricane Boundary Layer Inflow Experiment** (J. Zhang, E. Uhlhorn, J. Cione)
Goal: Directly measure the thermodynamic and kinematic structure of the hurricane inflow layer radially and vertically to the best extent possible. Refer to the HFP Boundary Layer Inflow experiment and SUAVE (module 3) for additional details.
Model evaluation component: The near-surface inflow is a crucial region of a tropical cyclone (TC), since it is the area of the storm in direct contact with the ocean moisture and heat sources which power the storm. Improved documentation of the storm inflow layer will enable detailed comparisons with numerical simulations. These comparisons should lead to subsequent improvements in physical representativeness of the inflow layer in operational models.

3) **SUAVE** (Cione)
Goal: utilize observations from unmanned aerial vehicles to enable enhanced high resolution comparisons between tropical cyclone boundary observations of temperature, moisture and wind with similar thermodynamic and kinematic output from NOAA’s regional and global operational models. Refer to the HFP SUAVE for additional details.
Model evaluation component: Given the inherent difficulty of flying manned aircraft at very low altitudes in a tropical cyclone, utilization of low altitude UAS has drawn significant interest in recent years. Given the preponderance of ‘instantaneous’ data collection within this region of the storm (GPS, SFMR), UAS offer a unique opportunity to expand beyond today’s limited data collection techniques by continuously sampling pressure, temperature winds and moisture within the low-level hurricane boundary layer environment. Such efforts, should improve future model initialization and validation efforts.

4) **RAPX** (Kaplan, Rogers, Dunion)
Goal: 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 24-72 h. Note: Will require modification to a 24h aircraft refresh cycle. Refer to the HFP RAPX for additional details.
Model evaluation component: Recent analyses of airborne Doppler and dropsonde data have shown statistically significant differences in both the environmental and the inner-core structures of TC’s that undergo RI from those that remain steady state. Such structures include the inner- and outer-core vorticity field, inflow depth and strength, and number and radial distribution of convective bursts. The data collected as a part of this experiment will span scales ranging from the environmental down to the convective and PBL scale. It will enable an evaluation of 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.

5) Microphysics - Aerosol/Cloud droplet measurement option (B. Black)
Goal: determine the natural range and number concentrations of the sub-cloud aerosol that is CCN in hurricanes that are far from land, unaffected by pollutants using new droplet spectra probes, a cloud liquid water meter, the Droplet Measurement Technologies (DMT) dual-chamber CCN counter, a DMT wide-band Integrated Bio-Aerosol sensor (WIBS-IV) and a CN counter. Refer to the HFP Microphysics experiment for additional details.
Model evaluation component: The observations collected herein will be utilized in due course for the evaluation of the HWRF model microphysics parameterizations. As presently configured, these parameterizations assume a fairly small number concentration of cloud droplets in the storm. These numbers derive from observations in fair-weather marine cumuli conducted more than 30 years ago. Such an assumption might not be valid in a hurricane, where copious sea-salt aerosols are generated, as this affects the colloidal stability of the clouds.

6) SALEX-Arc Cloud Module (Dunion)
Goal: Collect observations in mid-level dry layers (e.g. the SAL) that are hypothesized to be a necessary ingredient for the formation of strong downdrafts and subsequent outflow boundaries & arc clouds. Target observations ahead of and behind arc cloud features to sample the horizontal gradients of temperature, moisture, and winds (e.g. outflow) from ~600 hPa to the surface. Refer to the HFP SALEX experiment for additional details.
Model evaluation component: Arc clouds in the periphery of TCs represent the leading edge of large outflow boundaries that bring cool, dry air and enhanced outflow into the lower levels of the atmosphere. These rarely observed environments are formed in the presence of precipitation falling through mid-level dry air and are hypothesized to limit short-term TC intensification. Thermodynamic and kinematic observations that are collected during this module will be used to evaluate the robustness of the operational coupled model forecast system to represent the SAL and arc cloud environments.

7) Doppler Wind Lidar (DWL) Boundary-layer Module (J. Zhang)
Goal: Characterize the distribution and variations of kinematic boundary layer heights in hurricanes. Identify and document the characteristics of organized eddies such as boundary-layer rolls. Refer to the HFP DWL Boundary Layer module for additional details.
Model evaluation component: Boundary layer rolls are quasi-two dimensional features that can affect the surface flux transport and modulate the mean boundary layer structure. Observations that are collected during this experiment module will be used to evaluate the robustness of the operational coupled model forecast system (e.g. HWRF) to represent boundary layer rolls.

8) Doppler Wind Lidar (DWL) SAL Module (Dunion)
Goal: Characterize the suspended Saharan dust and mid-level (~600-800 hPa) easterly jet that are associated with the SAL with a particular focus on SAL-TC interactions. Observe possible impingement of the SAL's mid-level jet and suspended dust along the edges of the storm's (AEW's) inner core region (R=~150 km). Refer to the DWL SAL module for additional details.
Model evaluation component: The SAL's mid-level easterly jet and low- to mid-level dry air will be sampled using a combination of observations collected from GPS dropsondes and the P3DWL. Thermodynamic and kinematic observations that are collected during this module will be used to evaluate the robustness of the operational coupled model forecast system to represent the SAL's low humidity and embedded mid-level easterly jet.

9) TC Diurnal Cycle Experiment (Dunion)
Goal: Sample the thermodynamic and kinematic environment of diurnal pulses at various stages of their life cycles, including their initial formation and subsequent evolution, and to observe any corresponding fluctuations in TC structure and intensity during these events. Employ both NOAA P-3 and G-IV aircraft to collect kinematic and thermodynamic observations both within the inner-core (i.e., radius <200 km) and in the surrounding large-scale environment (i.e., 200 km < radius ≤400 km) for systems that have exhibited signs of diurnal pulsing in the previous 24 hours. Employ the NOAA G-IV jet to sample the temperature, moisture, and winds at the TC cirrus canopy level before, during, and after the time of local sunset. Note: Will require modification to a 24h aircraft refresh cycle. Refer to the HFP TC Diurnal Cycle experiment for additional details.
Model evaluation component: The predictable propagation of TC diurnal pulses in both space and time each day makes them fairly easy to sample at various radii around the storm. Thermodynamic and kinematic observations will be made of the diurnal pulses from the surface to the cirrus canopy and will include outflow layer sampling, as well as areas of enhanced convergence, moisture, or vertical motions at various levels of the troposphere. Thermodynamic and

kinematic observations that are collected during this module will be used to evaluate the robustness of the operational coupled model forecast system to represent the TC diurnal cycle.

10) TC in Shear Experiment (Reasor)
Goal: Examine changes in the structural evolution, convective asymmetry, intensity change, and moisture envelope (TC isolation) of TCs experiencing a significant increase in environmental wind shear. Note: Will require modification to a 24h refresh cycle. Refer to the HFP TC in Shear experiment for additional details.
Model evaluation component: It is widely accepted that vertical shear can have a significant impact on tropical cyclone structure and intensity change. A goal of this experiment is to better diagnose, quantitatively how, and to what extent, vertical shear effects hurricane structure, intensity and intensity change.

11) Convective Burst Module (Rogers)
Goal: 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. Refer to the HFP Convective burst module for additional details.
Model evaluation component: The data collected will be useful for evaluating the model-generated fields of vertical velocity, hydrometeor concentration, and reflectivity. Vertical profiles of the structure and high-frequency evolution of the mean and distribution (e.g., via contoured frequency by altitude diagrams) of these fields, along with derived properties such as vertical mass flux, will be calculated from the airborne radar. These fields will be compared with model output to evaluate the performance of the microphysical parameterization scheme and provide a benchmark for comparing potential changes to the formulation of the microphysical and planetary boundary layer parameterizations.

Oceanic component

Significance and Goals:

This component of the experiment broadly addresses improving understanding of the ocean's role in air-sea interaction and controlling TC intensity by making detailed measurements of these processes in storms. Specific science goals are in two categories:

Goal: To observe and improve our understanding of the upper-ocean response to the near-surface wind structure during TC passages. Specific objectives are to:

1. Quantify the influence of the underlying ocean on atmospheric boundary layer thermodynamics and ultimately storm intensity.

2. Quantify the capabilities of the operational coupled model forecast system to accurately capture and represent these processes

In addition, these ocean datasets fulfill needs for initializing ocean components of coupled TC Forecast systems at EMC and elsewhere.

Rationale:

Ocean effects on storm intensity. Upper ocean properties and dynamics play a key role in determining TC intensity. Modeling studies show that the effect of the ocean varies widely depending on storm size and speed and the preexisting ocean temperature and density structure. The overarching goal of these studies is to provide data on TC-ocean interaction with enough detail to rigorously test coupled TC models, specifically:

- Measure the two-dimensional SST cooling, air temperature, humidity and wind fields beneath the storm and thereby deduce the effect of the ocean cooling on ocean enthalpy flux to the storm.
- Measure the three-dimensional temperature, salinity and velocity structure of the ocean beneath the storm and use this to deduce the mechanisms and rates of ocean cooling.

- Conduct the above measurements at several points along the storm evolution therefore investigating the role of pre-existing ocean variability.
- Use these data to test the accuracy of the oceanic components coupled models.

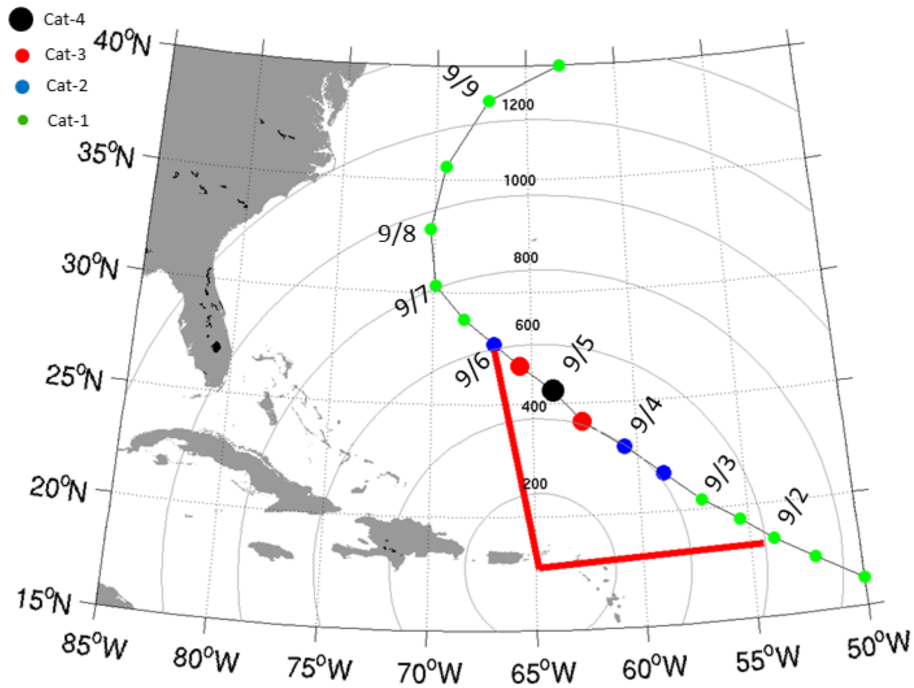

Figure 3-5: Storm track with locations plotted every 12 hours. of Range rings are 200 nmi relative to forward operating base at St. Croix, USVI (STX/TISX), and red line delineates storm locations within 600 nmi of STX. In this example, the storm center remains within 600 nmi for 4 days.

This multi-aircraft experiment is ideally conducted in geographical locales that avoid conflict with other operational requirements, for example, at a forward/eastward-deployed base targeting a storm not imminently threating the U.S. coastline. As an example, an optimal situation is shown in Fig. 3-5, with missions operating from St. Croix, USVI. A TC of at least minimal hurricane intensity is desired. In this example, the hypothetical storm remains within 600 nmi (a reasonable maximum distance) for four days, and at no time is forecasted to be a threat to land, including the U.S. coast.

3b-1. Expendable profiler surveys from P-3 aircraft

Flight sequence:

Pre-storm: To establish the pre-storm upper ocean thermal and mass structure prior to a storm's arrival, a pre-storm expendable survey will be conducted. This mission will consist of deploying a large grid of AXCTDs/AXBTs to measure the three-dimensional temperature and salinity fields (Fig. 3-6). This flight would occur **48 hours prior to storm arrival**, based primarily on the forecasted track, and optimally covers the forecast cone-of-error. A total of **50-60 probes** would be deployed, depending on mission duration, and spaced approximate 0.5 deg. apart. The experiment is optimally conducted where horizontal gradients are relatively small, but AXCP probes may be included if significant gradients (and thus currents) are expected to be observed. Either P-3 aircraft may be used as long as it is equipped with ocean expendable data acquisition hardware.

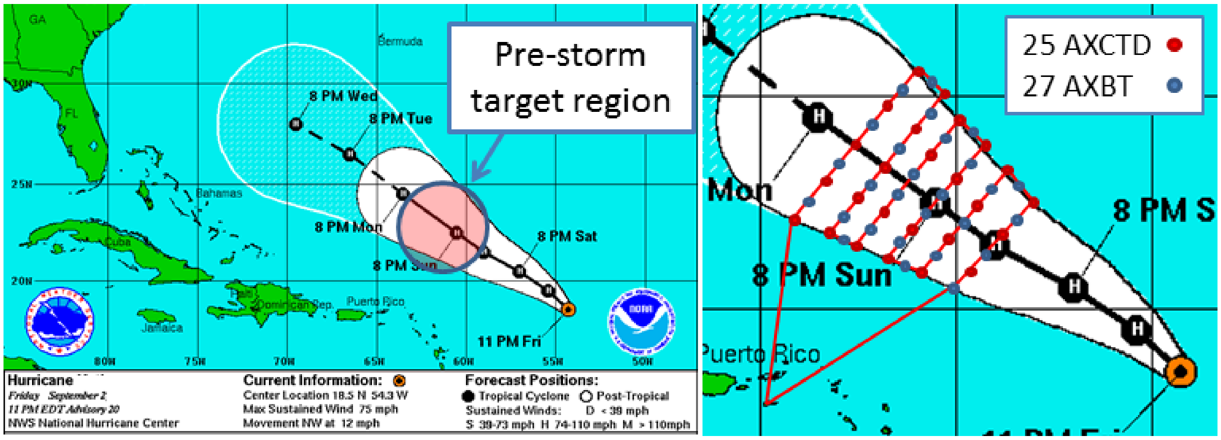

Figure 3-6: Left: NHC official forecast track, which pre-storm ocean sampling region highlighted. Target region is centered ~48 hours prior to forecast arrival of storm. Right: P-3 flight track (red line) and ocean sampling pattern consisting of a grid of AXCTD/AXBT probes Probes are deployed at ~0.5 deg. intervals. Total time for this pattern is estimated to be ~9 hours.

In-storm: Next, a mission is executed within the storm over the ocean location previously sampled (Fig. 3-7). This flight shall by conducted by the **P-3 carrying the Wide-swath Radar Altimeter (WSRA)** for purposes of mapping the two-dimensional wave field. The flight pattern should be a **rotated Figure-4**, and up to **20 AXBTs** should be deployed in combination with GPS dropwindsondes. Note that other experimental goals can and should be addressed during this mission, and a multi-plane mission coordinated with the other P-3, as well as G-IV, is desirable.

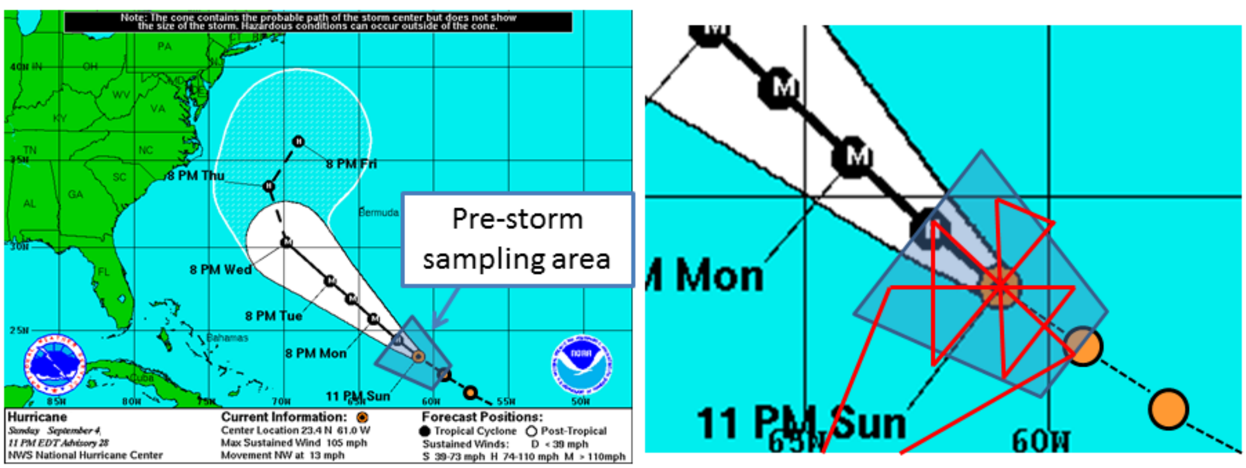

Figure 3-7: Left: NHC official forecast track at time of in-storm mission, with pre-storm sampled region highlighted. Right: P-3 in-storm flight pattern centered on storm and over previously-sampled ocean area. Typical pattern is expected to be a rotated Fig-4. Total flight time ~8 hrs.

Post-storm: Finally, a post-storm expendable survey shall be conducted over the same geographical location to assess ocean response, with slight pattern adjustments made based on the known storm track (Fig. 3-8). Approximately **60-70 probes** would be deployed (depending on duration limits), consisting mainly of **AXBTs/AXCPs** to map the three-dimensional temperature and currents, ideally 1-2 days after storm passage. In the Fig. 3-8 example, the pattern extends 470 km along the storm track, which in this example is ~0.75Λ, where $\Lambda = 2\pi V/f$ is the inertial wavelength. Ideally, up the pattern should extend up to 1Λ to resolve a full ocean response cycle. The storm speed V and flight duration limits will dictate whether this is possible. As for the pre-storm survey, either

P-3 may be used.

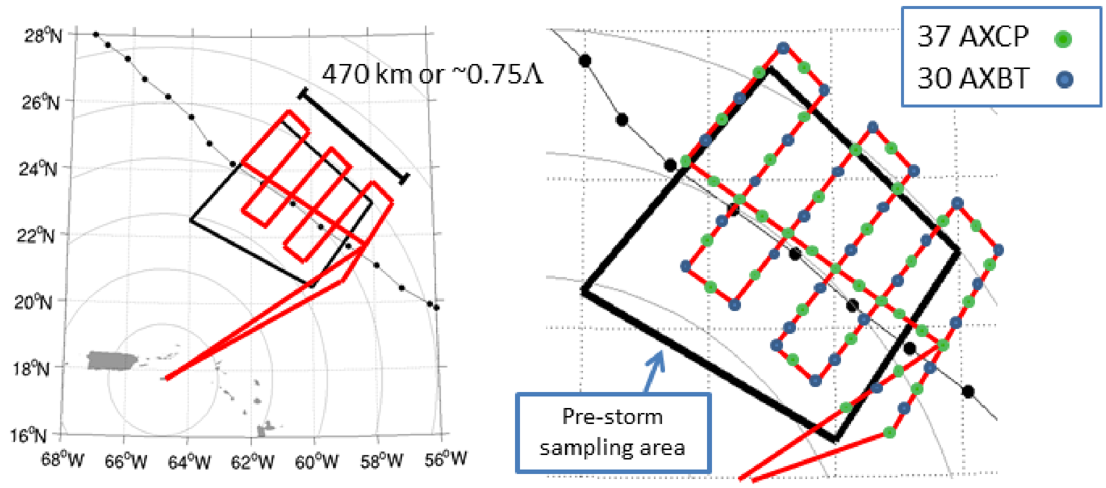

Figure 3-8: Left: Post-storm ocean sampling flight pattern (red line), over previously-sampled area (black box). In this example, the pattern extends around 470 km in the along-track dimension, or around 0.75 of a near-inertial wavelength. Right: Flight pattern with expendable drop locations, consisting of a combination of AXCP and AXBT probes.

3b-2. Coordinated float/driftedeployment by AF C-130

Measurements will be made using arrays of drifters deployed by AFRC WC-130J aircraft in a manner similar to that used in the 2003 and 2004 CBLAST program. Additional deployments have since refined the instruments and the deployment strategies. This work will be coordinated with P-3 deployments of AXBTs, AXCTDs and AXCPs to obtain a more complete picture of the ocean response to storms.

MiniMet drifters measure SST, sea level air pressure and wind velocity. Thermistor chain Autonomous Drifting Ocean Station (ADOS) drifters add ocean temperature measurements to 150m. All drifter data are reported in real time through the Global Telecommunications System (GTS) of the World Weather Watch. An additional stream of real-time, quality controlled data is also provided by a server located at the Scripps Institution of Oceanography. A number of E-M APEX Lagrangian floats will measure temperature, salinity and velocity profiles to 200m. Float profile data will be reported in real time on GTS.

Coordination and Communications

Alerts - Alerts of possible deployments will be sent to the 53rd AWRO up to 5 days before deployment, with a copy to CARCAH, in order to help with preparations. Luca Centurioni (SIO) and Rick Lumpkin (PhOD) will be the primary point of contact for coordination with the 53rd WRS and CARCAH.

Flights:
Coordinated drifter deployments would nominally consist of 2 flights, the first deployment mission by AFRC WC-130J and the second overflight by NOAA WP-3D. An option for follow-on missions would depend upon available resources.

Day 1- WC-130J Float and drifter array deployment- Figure 3-9 shows a possible nominal deployment pattern for the float and drifter array. It consists of two lines, A and B, set across the storm path with 8 and 4 elements respectively. The line length is chosen to be long enough to span the storm and anticipate the errors in forecast track, and the lines are approximately in the same location as the pre-storm P-3 expendable probe survey. Instrumentation should be deployed 24-48 hours prior to storm arrival. The element spacing is chosen to be approximately the RMW. In case of large uncertainties of the forecast track a single 10 node line is deployed instead. The thermistor chain drifters (ADOS) are deployed near the center of the array to maximize their likelihood of seeing the maximum wind speeds and ocean response. The Minimet drifters are deployed in the outer regions of the storm to obtain a full section of storm pressure and wind speeds. The drifter array is skewed one element to the right of the track in order to sample the stronger ocean response on the right side (cold wake).

Day 2. P-3 In-storm mission- The in-storm mission will be conducted by the P-3 as previously described. Efforts will be made to deploy AXBTs during the mission near the locations of drifters/floats as reported in real time. It is highly desirable that this survey be combined with an SRA surface wave survey because high quality surface wave measurements are essential to properly interpret and parameterize the air-sea fluxes and boundary layer dynamics, and so that intercomparisons between the float wave measurements and the SRA wave measurements can be made.

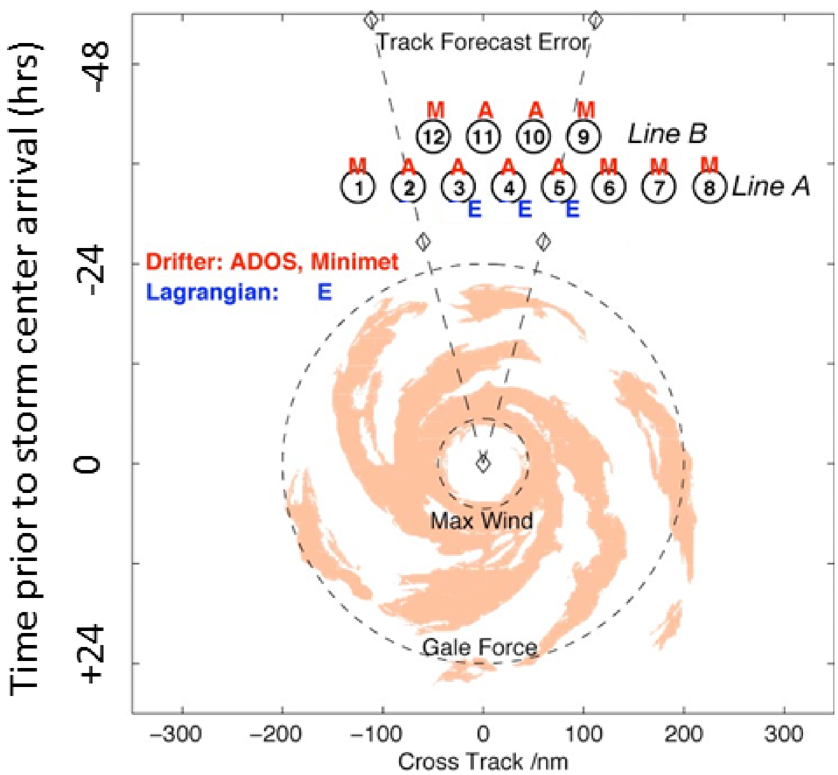

Figure 3-9: Drifter array deployed by AFRC WC-130J aircraft. The array is deployed ahead of the storm with the exact array location and spacing determined by the storm speed, size and the uncertainty in the storm track. The array consists of ADOS thermistor chain (A) and minimet (M) drifters, and EM-APEX Lagrangian floats (E). Two items are deployed at locations 3, 4 and 5, and one item elsewhere.

2b-3 Ocean glider deployments

To complement the aircraft-based experiments, it is also a goal to test the new observation capabilities of ocean gliders in hurricanes. For the first time, current velocity profiles will be obtained from Seagliders to assist hurricane forecast models to reproduce the key ocean dynamic processes associated with tropical storm-induced surface ocean cooling. The main objectives of the proposed work are to implement upper ocean observations from Seagliders, to evaluate their impact on and to improve: (1) hurricane intensity forecasts and (2) hurricane seasonal forecasts; using a combination of these new sustained observations, targeted observations, data analysis, and current NOAA operational forecast models. Of critical importance will be the joint analysis of the data collected through this project with those obtained through targeted observations, WP-3D and WC-130J flights that deploy a suite of atmospheric sensors.

3.1. Ocean Observations

A pilot array of two Seagliders will be deployed to carry out sustained and targeted upper-ocean profiling of temperature (T), salinity (S), and current velocities (u,v) in the AWP region (Figure 3-10). Seagliders are cost-effective observational underwater vehicles used for targeted and sustained upper-ocean T, S, and (u,v) observations, they operate easily in open waters, even under hurricane strength winds, and can be navigated across moderately strong currents. The Seagliders are durable, autonomous, and have a low-drag and hydrodynamic shape and use battery power to control their buoyancy to move vertically, and use their wings to guide themselves forward along a remotely programmed trajectory (Eriksen et al. 2001). When their batteries run out, the Seagliders can be recovered and then refurbished and redeployed immediately. Their small size (~2m long) and low weight (~50 kg) allow for an easy deployment and recovery by two people from a small vessel. Seagliders transit at approximately 20-25 km/day while executing 8-10 T-S profiles/day to 1,000 meters and of (u,v) to 200m. They can navigate approximately 4,000 km and collect and transmit about 1,600 profiles during a 6- month deployment. While surfaced, they can also download any new instructions for altering the navigation route. Data will be transmitted in real-time into the GTS. In this work, each Seaglider will provide data of approximately 2,700 profiles per year.

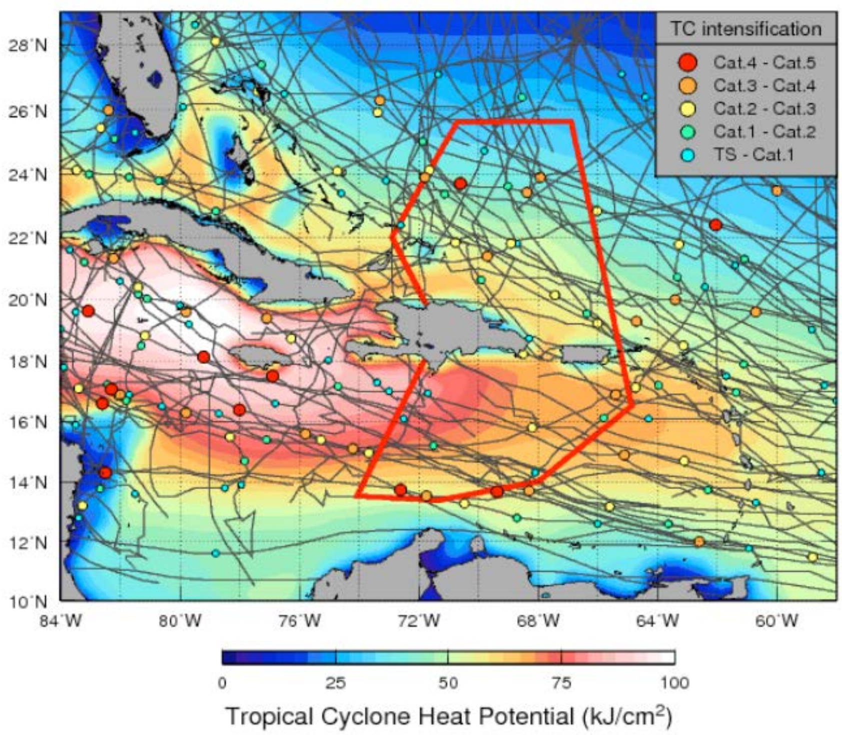

Figure 3-10. The two regions (bounded with red lines) where Seagliders will be deployed. Tracks of Cat. 1-5 cyclones (in grey) in a region of the AWP during 1993-2011, with circles indicating the location of their intensifications. The background color is the Tropical Cyclone Heat Potential (proportional to the upper ocean heat content).

2b-4 AXBT deployments by TROPIC on AF C-130

In addition to the P-3 expendable ocean probe deployments described above, additional ocean temperature profiles will be obtained by AFRC WC-130J aircraft as part of the Training and Research in Oceanic and Atmospheric Processes in Tropical Cyclones (TROPIC) program under the direction of CDR Elizabeth Sanabia, Ph.D. (USNA). Several overlapping mission goals have been identified providing an additional opportunity for collaboration and enhancing observational data coverage. See www.onr.navy.mil/reports/FY11/mmsanabi.pdf for details.