MATURE STAGE EXPERIMENT
Science Description

Experiment/Module: Research In Coordination with Operations Small Uncrewed Air Vehicle Experiment (RICO SUAVE)

Investigator(s): Joseph Cione, Jun Zhang, Josh Wadler, George Bryan (NCAR), Ron Dobosy (NOAA/ARL-ret), Altug Aksoy, Sim Aberson, Frank Marks, Kelly Ryan, Brittany Dahl, Xiaomin Chen, Johna Rudzin-Schwing, (MS State), Josh Alland (NCAR), Rosimar Rios-Berrios (NCAR), Evan Kalina (NOAA/DTC), Don Lenschow (NCAR), Chris Rozoff (NCAR), Eric Hendricks (NCAR), Falko Judt (NCAR), Jonathan Vigh (NCAR)

Requirements: Categories 2–5

Plain Language Description: This experiment uses small drones, instead of crewed aircraft, to sample the lowest and most dangerous regions of the tropical cyclone (TC). It is believed that observations from these unique platforms will improve basic understanding and enhance forecaster situational awareness. Detailed analyses of data collected from these small drones also have the potential to improve the physics of computer models that predict changes in storm intensity.

Mature Stage Science Objective(s) Addressed:

1) Test new (or improved) technologies with the potential to fill gaps, both spatially and temporally, in the existing suite of airborne measurements in mature hurricanes. These measurements include improved three-dimensional representation of the hurricane wind field, more spatially dense thermodynamic sampling of the boundary layer, and more accurate measurements of ocean surface winds and underlying oceanic conditions [*APHEX Goal 2*].
2) Collect observations targeted at better understanding internal processes contributing to mature hurricane structure and intensity change [*APHEX Goals 1, 3*].

Motivation: Reducing the uncertainty associated with TC intensity forecasts remains a top priority of NWS/NHC. In addition to NOAA's operational requirements (sampling surface wind and thermodynamic structure), developing the capability to regularly fly low altitude small uncrewed aircraft system (sUAS) into TCs helps to advance NOAA research by allowing scientists to sample and analyze a region of the storm that would otherwise be impossible to observe in detail (due to the severe safety risks associated with crewed reconnaissance). It is believed that such improvements in basic understanding are likely to improve future numerical forecasts of TC intensity change. Over time, projects such as this, which explore the utilization of unconventional and innovative technologies in order to more effectively sample critical regions of the storm environment should help reduce this inherent uncertainty. Coordination with uncrewed ocean surface vehicles (saildrones) in a hurricane, if the opportunity arises, will enable for the first time collocated measurements of the upper ocean, air-sea interface, and atmospheric boundary layer from autonomous vehicles.

Background: The Area-I Altius 600 is an electric-powered sUAS that has 3-5 h of endurance with up to a 150nmi range. It has a wingspan of 8 feet and a gross weight of 25lbs. Once airborne, the sUAS collects in-situ measurements of pressure, temperature, relative humidity (PTHU), and remotely senses sea surface temperature. The three-dimensional winds are also determined using information from the aircraft's autopilot. In some ways, the Altius 600 sUAS is similar to the GPS dropsonde since both observing platforms are air-deployed and both use identical (Vaisala RD41) meteorological payloads. However, unlike the dropsonde, the Altius 600 can target specific areas within the storm circulation in detail (both in the horizontal and in the vertical). Furthermore, observations from the Altius 600 are continuous (~5Hz) and long duration (hours versus minutes) which gives scientists an extended look into important small-scale thermodynamic and kinematic turbulent processes that regularly occur within the near-surface TC boundary layer (Cione et al. 2016, Cione et al. 2020). The Altius 600, when operated within a hurricane environment, will provide a unique observation platform to observe the low-level atmospheric boundary layer and sea surface environment in great detail.

It should also be noted that two additional sUAS (Barron Associates' Wingsonde and Black Swift Technologies S0) are also expected to be available during the 2022 HFP. The endurance for both drones should be 1-2h with similar P-3-to-drone range expected from the Altius 600 (150nmi). These smaller drones (3-9lbs, 4-5ft wingspan) will also measure PTHU and remotely sensed sea surface temperature. Three-dimensional winds will also be available using these aircraft.

Goal(s): This module aims to collect PTHU observations within the high wind eyewall and boundary layer inflow regions of mature hurricanes. A primary goal is to provide real-time data of winds to improve operational situation awareness (RMW, VMax). An equally important, albeit longer-term goal, is to improve basic understanding of a sparsely-sampled, yet critically important region of the storm where turbulent exchanges of heat, moisture, and momentum with the ocean and eye-eyewall interfaces regularly occur. These observational data will also be used to evaluate operational model performance as it relates to boundary layer thermodynamic and kinematic structure and SST ocean response.

Hypotheses:

1. 360-degree depictions of hurricane boundary layer RMW and Vmax at multiple altitudes are possible by conducting UAS eyewall orbit missions by strategically synchronizing the prevailing wind direction with UAS heading.
2. Accurate depictions of the TC thermodynamic and kinematic inflow layer (100-1500m) are possible using dropsonde and sUAS strategically deployed observations and can yield information about important physical processes that control TC intensity.
3. Eye loitering, TC center fixes, and eye-eyewall targeting sampling are possible using sUAS.

Objectives:

1. Eyewall module: Make sUAS HDOBS available in near-real-time to NHC; Report estimates of RMW and Vmax at multiple altitudes and azimuths to NHC in near-real-time. In post-storm mode, conduct analyses comparing sUAS atmospheric and SST high wind eyewall observations with operational analysis and forecast fields from HWRF and HAFS.

All sUAS data collected should be available in KARMA (AOC's P-3 situational awareness visualization tool).

2. Inflow module: Make sUAS HDOBS available in near-real-time to NHC and EMC. In post-storm mode, compare sUAS TC boundary layer thermodynamic and kinematic radial structure (including SST) with numerical equivalents to improve TC boundary layer parameterizations and ocean response in HWRF and HAFS. Also, use sUAS HDOBS to improve our understanding of the role of downdrafts in determining TC intensity as well as the turbulent structure of the TC boundary layer.
3. Center fix/Eye-Eyewall module: Make sUAS HDOBS available in near-real-time to NHC and EMC. Report center fix estimates to NHC in near-real time. In post-storm mode, compare sUAS TC boundary layer thermodynamic and kinematic and SST structure within the eye and eye/eyewall interface with numerical equivalents to improve TC boundary layer parameterizations and ocean response in HWRF and HAFS.

Aircraft Pattern/Module Descriptions (see *Flight Pattern* document for more detailed information):

P-3 Pattern #1: sUAS Eyewall Circumnavigation
This P-3 module can be conducted using any pattern that maximizes azimuthal eyewall coverage and will collect flight level, TDR, dropsonde, AXBT, and SFMR observations for sUAS comparison and validation. The P-3 pattern should maximize eyewall sampling and penetration count. Dropsondes, SST-capable dropsondes, and AXBTS (10-15 total) will be deployed in locations that are collocated with sUAS under flights.

P-3 Pattern #2: sUAS Inflow
With the ideal sUAS inflow module starting in the upshear-left quadrant, the ideal P-3 pattern starts with a radial penetration from the downshear-right to the upshear-left quadrant. After release of the sUAS, the P-3 continues its standard flight pattern. After the second radial leg, it is preferable that the P-3 flies a similar flight path as the sUAS, where dropsondes, SST-capable dropsondes, and AXBTS (10-15 total) will be deployed every 30 degrees in azimuth in locations that are collocated with sUAS under flights. The P-3 will collect flight level, TDR, CRL, dropsonde, AXBT, and SFMR observations for sUAS comparison and validation.

P-3 Pattern #3: sUAS Center Fix/Eye Loiter/Eye-Eyewall Sampling Module
This P-3 module can be conducted using any pattern that maximizes inner core coverage and will collect flight level, TDR, dropsonde, AXBT, and SFMR observations for sUAS comparison and validation. Dropsondes, SST-capable dropsondes, and AXBTS (10-15 total) will be deployed in locations that are collocated with sUAS under flights.

Links to Other Mature Stage Experiments/Modules: The RICO SUAVE Experiment can be flown in conjunction with following *Mature Stage* experiments and modules: Boundary Layer and Air-Sea Interactions, Eye-Eyewall Mixing, Gravity Wave, Convective Burst Structure and Evolution, Rainband Complex Survey, Surface Wind Speed, and Significant Wave Height

Validation, TC Diurnal Cycle, Synoptic Flow, NESDIS JPSS Satellite Validation, ADM-Aeolus Satellite Validation, and NESDIS Ocean Winds.

Analysis Strategy: The analysis of these data includes two components: understanding hurricane boundary layer structure and potential improvements to hurricane prediction that sUAS observations can provide. Existing working groups are currently analyzing sUAS data and are focused on two main areas: boundary layer turbulence and thermodynamics, and observing system experiments (OSEs). Data from these sUAS missions can resolve small-scale features and physical processes that can then be compared and contrasted with similar boundary layer representations from multiple numerical models (HWRF, HAFS, CM1). In addition, research involving OSEs and observing system simulation experiments (OSSEs) will be used to help quantify the impact of sUAS observations and allow help optimize sUAS resources by comparing observing strategies generated from a Nature Run.

References:
Cione, J.J., G. Bryan, R. Dobosy, J. A. Zhang, G. de Boer, A. Aksoy, J. Wadler, E. Kalina, B. Dahl, K. Ryan, J. Neuhaus, E. Dumas, F. Marks, A. Farber, T. Hock and X. Chen 2020: Eye of the Storm: Observing Hurricanes with a Small Unmanned Aircraft System. *Bull. Amer. Meteor. Soc.* *https://doi.org/10.1175/BAMS-D-19-0169.1*

Cione, J. J., E. Kalina, E. Uhlhorn, and A. Damiano 2016: Coyote Unmanned Aircraft System Observations in Hurricane Edouard (2014). *Earth Space Sci.*, doi:10.1002/2016EA000187.