MATURE STAGE EXPERIMENT
Science Description

Experiment/Module: Tail Doppler Radar (TDR) Experiment

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Requirements: Categories 2-5

Early Stage Science Objective(s) Addressed:

1) Collect observations targeted at better understanding the response of mature hurricanes to their changing environment, including changes in vertical wind shear, moisture and underlying oceanic conditions [*IFEX Goals 1, 3*]

2) 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 TC wind field, more spatially dense thermodynamic sampling of the boundary layer, and more accurate measurements of ocean surface winds [*IFEX Goal 2*]

Motivation: This experiment is a response to the requirement listed as Core Doppler Radar in Section 5.4.2.9 of the National Hurricane Operations Plan (NHOP). The goal of that particular mission is to gather airborne-Doppler wind measurements that permit an accurate initialization of the Hurricane Weather Research and Forecasting (HWRF) model, and also provide three-dimensional wind analyses for forecasters. 2019 will be the first year that the TDR analyses will be available in AWIPS-II for hurricane forecasters at NHC, CPHC, and any other forecast office that would find the analyses helpful.

This particular experiment, though a required one because of operations, also provides numerous cases for developing composite and statistical studies of hurricanes.

Background: The real-time analysis of tail Doppler radar data was made possible by an automated quality control process (Gamache 2005) and variational wind synthesis method (Gamache 1997; Reasor et al. 2009). This permits the quality-control of all TDR-experiment TDR data sets in a timely manner, to support case studies, and even more importantly composite and statistical studies of hurricanes.

Hypotheses:

1. Improving representation of a storm's inner core in the HWRF initial conditions through assimilation of P-3 and G-IV TDR data leads to reduced error in short-term structure and intensity forecasts.

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

P-3 Patterns: NOAA will conduct a set of flights during several consecutive days, encompassing as much of a particular storm life cycle as possible. This would entail using P-3s on back-to-back flights on a 12-h schedule when the system is at depression, tropical storm, or hurricane strength.

The TDR experiment is an experiment that spans the entire life-cycle, so it is covered here as well as in the early-stage experiments. Since the TDR experiment is generally performed several times a year, as an experiment tasked by EMC, NHC, or CPHC, it is unexpected that it would be carried out as described without such a tasking, to allow for other experiments to have a chance. Whenever possible that a good description of the TC can be obtained in well under 9 hours, other modules would be flown in conjunction with TDR, especially since the TDR experiment provides a good background description of a system within which the module is performed.

The target will be a mature hurricane. In the best-case scenario, it will have followed on directly from the early-stage TDR experiment. The other reason this experiment would be tasked is if the United States or its territories are under threat. At this stage of hurricane development, the system is likely to be more vertically coherent, unless it is moving rapidly over cool water, or is subjected to intense shear. Either way, the extent of the system will still require that the best option is to document wavenumbers 0 and 1 over a wider range of radii, rather than more wavenumbers over a narrower range of radii. These patterns would be a figure-4, butterfly pattern, or rotating figure 4, depending on system size and distance from base of operations.

The highest vertical resolution is needed in the boundary and outflow layers. This is assumed to be where the most vertical resolution is needed in observations to verify the initialization and model. For this reason, it is desirable that *if sufficient dropwindsondes are available*, they should be deployed in the radial penetrations to verify that the boundary layer and surface wind forecasts produced by HWRF resemble those in observations. These observations will also supplement airborne Doppler observations, particularly in sectors of the storm without sufficient precipitation for radar reflectivity (likely from intense shearing). *If sufficient dropwindsondes are not available*, a combination of SFMR and airborne Doppler data will be used for verification.

G-IV Patterns: The ultimate requirement for EMC is to obtain the three-dimensional wind field of Atlantic TCs from airborne Doppler data every 6 h to provide an initialization of HWRF through assimilation every 6 h. The maximum possible rotation of missions is two per day or every 12 h. The TDR on the G-IV is now officially considered operational; therefore, velocity data will be transmitted in real-time to EMC. We recommend storm overflight whenever possible during synoptic surveillance missions. The most effective pattern, fulfilling the needs for inner-core assimilation and the current operational requirement for synoptic measurement, will be refined through experiments using the Hurricane Ensemble Data Assimilation System (HEDAS) and consultation with NHC and EMC.

Beyond operationally-tasked G-IV missions, among some specific scenarios in which this experiment would be carried out are as follows: 1) at the conclusion of NHC tasking for a landfalling TC, likely coordinated with the P-3 aircraft; 2) prior to NHC tasking for a TC of interest to EMC (priority is coordination with P-3 aircraft); 3) a recurving TC (priority is coordination with P-3 aircraft). Since coordination with the P-3 aircraft is an early requirement, this experiment would have to be weighed against other experiments, which stagger the P-3 and G-IV flight times. This initial coordination is necessary for 1) comparing and synthesizing storm structure derived from the two radar platforms and 2) the most thorough testing of HEDAS with this new data source. Subsequent flights may relax this requirement for P-3 coordination as the quality of the G-IV data is established.

Links to Other Early Stage Experiments/Modules: The TDR Experiment can be flown in conjunction with following *Mature Stage* experiments and modules: Eye-Eyewall Mixing, Gravity Wave, SEF, and SFMR Modules, TCDC Experiment, TC in Shear Experiment, Synoptic Flow Experiment, NESDIS JPSS Satellite Validation Experiment, ADM-Aeolus Satellite Validation Module, and NESDIS Ocean Winds.

Analysis Strategy: The emphasis here is on "real-time" products. Quality-controlled, thinned (by radial averaging) Doppler radials are output, packaged and transmitted to NCEP Central Operations (NCO) for assimilation into the operational HWRF model. Similarly, Doppler radial superobs are transmitted for use by research groups. Three-dimensional and vertical profile analyses of wind and reflectivity are also produced. Plan-view images derived from the analyses are transmitted to NHC for inclusion in AWIPS. Additional products include composite analysis images with dropwindsonde winds overlaid and, most recently, wind and reflectivity structure images for real-time mission planning and viewing by NHC specialists.

The real-time three-dimensional Cartesian analyses in 2019 will be at 2 km resolution out to 250 km radius, and it is expected that we will have a return to full vertical profiles. Thus, a research quality data set will be available almost immediately, except in cases where even higher resolution is desired.

References:

Gamache, J. F., 2005: Real-time dissemination of hurricane wind fields determined from airborne Doppler radar data. National Hurricane Center, 38 pp. [Available online at http://www.nhc.noaa.gov/jht/2003- 2005reports/DOPLRgamache_JHTfinalreport.pdf.]

Reasor, P. D., M. Eastin, and J. F. Gamache, 2009: Rapidly intensifying Hurricane Guillermo (1997). Part I: Low-wavenumber structure and evolution. *Mon. Wea. Rev.*, **137**, 603–631.