EARLY STAGE EXPERIMENT
Science Description

Experiment/Module: Tail Doppler Radar (TDR) Experiment

Investigator(s): Paul Reasor (Co-PI), John Gamache (Co-PI)

Requirements: TD, TS, Category 1

Early Stage Science Objective(s) Addressed:

1) Collect datasets that can be used to improve the understanding of intensity change processes, as well as the initialization and evaluation of 3-D numerical models, particularly for TCs experiencing moderate vertical wind shear [*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 early stage TCs. 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.

There is some reason to believe that TDR data are particularly helpful in initializing simulated tropical cyclones that are less organized. The incremental improvement over flight-level data only are greater at this stage, when the tilt of the center with height is often greater than in mature systems, and when the vertical coherence is less.

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, particularly in weaker, less-organized tropical cyclones.

EARLY STAGE EXPERIMENT
Science Description

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 mature-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.

All other things being equal, the target will be an organizing tropical depression or weak tropical storm, to increase the observations available in these systems. One scenario could likely occur that illustrates how the mission planning is determined: an incipient TC, at depression or weak tropical storm stage is within range of an operational base and is expected to develop and remain within range of operational bases for a period of several days. Here, the highest priority would be to start the set of flights, with single-P-3 missions, while the TC is below hurricane strength (preferably starting at depression stage), with continued single-P-3 missions at 12-h intervals until the system is out of range or makes landfall. During the tropical depression or tropical-storm portion of the vortex lifetime, higher azimuthal resolution of the wind field is preferred over radial extent of observations, so the flight pattern may be a lawn-mower pattern, or a square spiral, in addition to figure-4 or butterfly patterns.

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. *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 will be 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 the following *Early Stage* experiments and modules: AIPEX, CBM, SFMR Module, DWL Module, Gravity Wave Module, Synoptic Flow Experiment, NESDIS JPSS Satellite Validation Experiment, and ADM-Aeolus Satellite Validation Module.

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, with 150-m vertical resolution, and at least 1.5-km horizontal resolution. 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.