MATURE STAGE EXPERIMENT
Science Description

Experiment/Module: Environment Interaction (TC in Shear) Experiment

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Requirements: Categories 2–5

Mature 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*]

Motivation: Although most TCs in HRD's data archive experience some degree of vertical wind shear (VWS), the timing of flights with respect to the shear evolution and the spatial sampling of kinematic and thermodynamic variables have not always been carried out in an optimal way for testing hypotheses regarding shear-induced modifications of TC structure and their impact on intensity change (see below). This objective will sample the TC at distinct phases of its interaction with VWS and measure kinematic and thermodynamic fields with the azimuthal and radial coverage necessary to test existing hypotheses.

Background: Riemer et al. (2010) and Riemer et al. (2013) have proposed an intensity modification mechanism rooted in a balance-dynamics framework. They argue that balanced vorticity asymmetry at low levels, generated outside the core through shear forcing, organizes convection outside the eyewall into a wavenumber-1 pattern through frictional convergence. Downdrafts associated with this vortex-scale convective asymmetry arise as precipitation generated by the convective updrafts falls into unsaturated air below. In their simulations, the downdrafts led to a vortex-scale transport of low equivalent potential temperature (θe) air into the inflow layer and disruption of the TC heat engine (Emanuel 1986, 1991). If particularly low θe air at lower to middle levels of the environment is able to reach the core region where convective enhancement occurs, the thermodynamic impacts of the downward transport of low θe air would be enhanced. Riemer and Montgomery (2011) proposed a simple kinematic model for this environmental interaction, quantifying the shear-induced distortion of the "moist envelope" surrounding the TC core as a function of shear strength, vortex size, and vortex intensity.

In the simulations of Riemer et al. (2010), the TC core region developed vertical tilt following its initial encounter with VWS, but then realigned, i.e., the vortex was resilient. As the TC realigned, intensification resumed. The problem of dynamic resilience focuses on the ability of the TC to maintain a vertically-coherent vortex structure as it experiences vertical shearing. Jones (1995) found that coupling between vertical layers, and the tendency for the upper- and lower-level potential vorticity (PV) of the cyclonic core to precess upshear, restricts the development of vertical tilt that would otherwise occur through differential advection. For small-amplitude tilt, Reasor et al. (2004) developed a balance theory for the shear forcing of vortex tilt in which the tilt asymmetry behaves as a vortex-Rossby wave. In this vortex-Rossby wave framework, they developed a heuristic model for the TC in shear, which predicts a left-of-shear tilt equilibrium. Furthermore, they demonstrated that the evolution towards this equilibrium tilt state depends not only on intrinsic scales of the flow (e.g., Rossby number and Rossby deformation radius), but also on the radial distribution of (potential) vorticity in the core region. Reasor and Montgomery (2015) have recently evaluated this heuristic model. The model is capable of predicting the enhancement of resilience that arises as the PV gradient outside the core increases. Even when moist neutral conditions exist within the eyewall, the model still describes the long-time evolution of the tilt asymmetry outside the eyewall.

Hypotheses:

1. Vertical wind shear inhibits TC intensification through the downward transport of low-entropy air into the inflow layer outside the eyewall, brought on by vortex-tilt-induced organization of convection there. Intensification resumes as the TC realigns and the shear-induced weakening pathway diminishes.

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

P-3 Pattern 1: Prior to an increase in vertical wind shear, perform a Figure-4 pattern (orientation chosen for efficiency) with TDR to obtain the TC core structure. As time permits, the aircraft executes a second, rotated Figure-4 pattern.

P-3 Pattern 2: Following an increase in vertical wind shear (~12 h after P-3 Pattern 1), perform a single Figure-4 pattern with TDR to obtain the TC core-region structure. Then travel downwind to set up a rotated Figure-4 pattern with truncated radial legs. The radial legs should extend just outside the primary mesoscale region of convection radially beyond (~15–30 n mi/25-55km) the eyewall. Dropsondes should be launched within and downwind of the convective region outside the eyewall in such a way as to sample low-entropy air spiraling into the eyewall within the boundary layer. Repeat every 12 h.

G-IV Pattern 1: Perform storm-relative environmental TDR and dropsonde sampling through clockwise circumnavigation, starting at 150 n mi, moving inward to 90 n mi, and finishing at 60 n mi. This pattern should be coordinated with P-3 Pattern 1 during the pre-shear stage and then 24 h later with P-3 Pattern 2. A primary objective of the coordinated P-3 and G-IV dropsonde sampling is to document the evolution of the moist envelope surrounding the core.

Links to Other Mature Stage Experiments/Modules: The TC in Shear Experiment can be flown in conjunction with the following *Mature Stage* experiments and modules: Eye-Eyewall Mixing, Gravity Wave (TC upshear side), SEF (during shear forcing), and SFMR Modules, TDR Experiment, TCDC Experiment (e.g., arc clouds on upshear side), Synoptic Flow Experiment, NESDIS JPSS Satellite Validation Experiment, ADM-Aeolus Satellite Validation Module, and NESDIS Ocean Winds.

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Analysis Strategy: The basic analysis follows that presented in recent observational studies of the vertically sheared TC (Reasor et al. 2009; Reasor and Eastin 2012; Reasor et al. 2013; Rogers et al. 2013; Zhang et al. 2013). The analysis includes: low-wavenumber kinematic structure of the core region above the boundary layer, vortex tilt, and local VWS derived from airborne Doppler radar observations; low-wavenumber kinematic structure of the boundary layer derived from SFMR and dropsonde measurements; low-wavenumber thermodynamic structure within and above the boundary layer derived from dropsondes and flight-level measurements; and convective burst statistics derived from Doppler radar observations. New elements of the analysis will include: 3D kinematic structure out to at least 4–5xRMW using radar observations; low-wavenumber kinematic, thermodynamic, and moisture structures out to 150 n mi using G-IV radar and dropsonde observations; high azimuthal and radial representation of the inflow structure downwind of the mesoscale-organized convection radially outside the eyewall.

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