EARLY STAGE EXPERIMENT
Science Description

Experiment/Module: Stratiform Spiral Module (SSM)

Investigator(s): Rob Rogers (PI), Trey Alvey, Robert Black, Hua Leighton, Xuejin Zhang, Michael Bell (CSU), Anthony Didlake (PSU), Jim Doyle (NRL), Dan Stern (NRL), Josh Wadler (ERAU)

Requirements: TD, TS, Category 1

Plain Language Description: This module samples the distribution of cloud and rain droplets and ice and snow particles and how those distributions vary with altitude across the freezing level in broad regions of relatively weak precipitation and upward motion.

Early Stage Science Objective(s) Addressed:

1. Obtain a quantitative description of the distribution of liquid and frozen hydrometeors in stratiform precipitation to better understand the processes that govern these distributions and how they are represented in numerical models [*APHEX Goals 1, 3*].

Motivation: The objectives are to obtain a quantitative description of the distribution of liquid and frozen hydrometeors in stratiform precipitation to better understand the processes that govern these distributions and how they are represented in numerical models and to improve retrievals of stratiform microphysical properties by polarimetric radar.

Background: As deep convection matures, it typically transitions to predominantly stratiform precipitation characterized by different microphysical processes than during the active phase of convection (Houze 1997). Ice processes such as vapor deposition and aggregation take on a more dominant role as vertical motions become weaker, and evaporation below the melting level also becomes important. Dynamically, the shift from active convection with strong low-level convergence and vortex stretching to stratiform precipitation with mid-level convergence and low-level divergence has an impact on the vortex intensification (Bell and Montgomery 2019, Rogers et al. 2020, Stone et al. 2023), and may also play an important role in secondary eyewall formation (Didlake et al. 2018). In an early stage TC, the transition from convective to stratiform precipitation may occur in roughly the same location, but as the rotational wind speeds intensify the transition can occur cyclonically downwind (Didlake and Houze 2013, Foerster et al. 2014). The microphysical processes involved in this transition must be parameterized in high-resolution models but are not well-understood in TC precipitation (Feng and Bell 2018). Improved knowledge of the microphysical processes in stratiform precipitation and its representation in numerical models is important in reproducing the latent heating distribution; its variation as a function of TC intensity and azimuthal, radial, and vertical location within the TC circulation; and the response of the TC to it.

Goal(s): Obtain a quantitative description of the distribution of liquid and frozen hydrometeors in stratiform precipitation to better understand the processes that govern these distributions and how they are represented in numerical models. Precipitation probe measurements of stratiform regions in TCs can also help improve retrievals of stratiform microphysical properties by polarimetric radar.

Objectives: Spiral ascents in stratiform regions of deep convection at radii outside the RMW will provide microphysical measurements from in-situ probes, including how the microphysics vary in a shear-relative framework

1. Optimal additional measurements include:
    a. Deep-layer measurements of temperature and humidity in the local environment of the stratiform precipitation from high-altitude aircraft will provide the thermodynamic context within the mid-and lower troposphere
    b. Measurements of sea-surface temperature and subsurface temperature profiles from ocean probes and/or IR dropsondes will provide context on the surface boundary

Aircraft Pattern/Module Descriptions (see *Flight Pattern* document for more detailed information): This is a stand-alone module that takes 1–2 h to complete. Execution is dependent on system attributes, aircraft fuel and weight restrictions, and proximity to the operations base. It can be flown separately within a mission designed to study local areas of convection or at the end of one of the survey patterns. Once a local area of stratiform precipitation is identified, the P-3 will transit at altitude (10–12 kft) to the nearest point, where a spiral ascent and descent can be made to obtain direct hydrometeor measurements with the P-3 cloud and precipitation probes. This module can also be flown during the mature stage, in conjunction with the rainband module.

Links to Other Early Stage Experiments/Modules: SSM can be flown in conjunction with the following *Early Stage* experiments: *AIPEX*, *Convective Burst Module (CBM)*, *TDR Experiment*, and NESDIS *JPSS Satellite Validation Experiment* and the *Mature Stage Rainband Complex Module*. A crucial aspect of this module is that the kinematic and thermodynamic context of the vortex-scale structure is provided. Therefore, patterns that provide this context, through vortex survey patterns such as figure-4 and butterfly patterns, must be flown in conjunction with the CBM. *AIPEX* and the *TDR Experiment* are two good examples of this.

Analysis Strategy: Cloud and precipitation probe data will document the hydrometeor characteristics in the stratiform transition of deep convection, along with *in-situ* measurements of vertical velocity and thermodynamic information. A higher altitude dropsonde release at the apex of any spiral ascents will provide a deeper profile of thermodynamic structure.

Optimally, the G-IV will be flying in the storm to provide deep-layer humidity profiles around the storm in addition to the P-3 dropsondes. If spiral ascents are performed at larger radii in range of the G-IV radar then the in-situ and radar data can be synthesized to provide a more complete picture of the stratiform cloud dynamics.

References:

Bell, M. M., and M. T. Montgomery, 2019: Mesoscale Processes during the Genesis of Hurricane Karl (2010). *J. Atmos. Sci.*, **76**, 2235–2255, https://doi.org/10.1175/JAS-D-18-0161.1..

Didlake, A. C., and R. A. Houze, 2013: Dynamics of the stratiform sector of a tropical cyclone rainband. *J. Atmos. Sci*, **70**, 1891–1911.

Didlake, A.C., P.D. Reasor, R.F. Rogers, and W. Lee, 2018: Dynamics of the Transition from Spiral Rainbands to a Secondary Eyewall in Hurricane Earl (2010). *J. Atmos. Sci.,* **75**, 2909–2929, https://doi.org/10.1175/JAS-D-17-0348.1

Feng, Y.-C., and Bell, M. M, 2018: "Microphysical characteristics of an asymmetric eyewall in major Hurricane Harvey (2017)". *Geophys. Res. Lett., doi: 10.1029/2018gl080770.*

Foerster, A. M., M. M. Bell, P. A. Harr, and S. C. Jones, 2014: Observations of the eyewall structure of Typhoon Sinlaku (2008) during the transformation stage of extratropical transition. *Mon. Wea. Rev.*, **142**, 3372–3392.

Houze, R. A., 1997: Stratiform precipitation in regions of convection: A meteorological paradox? *Bull. Amer. Meteor. Soc.*, **78**, 2179–2196.

Rogers, R. F., P. D. Reasor, J. A. Zawislak, and L. T. Nguyen, 2020: Precipitation Processes and Vortex Alignment during the Intensification of a Weak Tropical Cyclone in Moderate Vertical Shear. *Mon. Wea. Rev*., **148**, 1899–1929, https://doi.org/10.1175/MWR-D-19-0315.1.

Stone, Z., G. R. Alvey III, J. P. Dunion, Fischer, M. S., D. J. Raymond, R. F. Rogers, S. Sentic, and J. Zawislak, 2023: Thermodynamic contribution to vortex alignment and rapid intensification of Hurricane Sally (2020). *Mon. Wea. Rev*., **151**, 931–951.