# MATURE STAGE EXPERIMENT
***Science Description***

---

**Experiment/Module:** TDR Dual-PRF in Hurricanes Module

**Investigator(s):** Paul Reasor and John Gamache

**Requirements:** Categories 2–5

**Plain Language Description:** A P-3 aircraft, flying through the eyewall and eye of a hurricane, will collect radar data while running the system in dual-PRF (Pulse Repetition Frequency) mode. Operating radars in this way is done to mitigate the occurrence of velocity ambiguities. The dataset will be used to test a method for correcting data errors introduced when operating in dual-PRF mode. A successful test may ultimately lead to implementation of a new approach to NOAA radar quality control that allows near real-time streaming of radar data from the aircraft rather than transmission only after a complete transect through the storm, as is presently done.

**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*]

**Motivation:** A dual-PRF technique permits extension of the Nyquist range of the TDR, reducing (or perhaps eliminating altogether) the need for dealiasing Doppler radial velocity in tropical cyclone environments. Running in dual-PRF mode, however, introduces new errors. The developmental dataset collected from this module will be used to test a method for correcting such errors and may ultimately lead to implementation of a new approach to NOAA TDR quality control that permits near real-time streaming of Doppler radials from the aircraft.

**Background:** Actual velocities measured by the TDR are folded/aliased within the Nyquist interval, which is approximately -22 to 22 m/s for the standard 2775 Hz PRF used during HRD missions. In major hurricanes, where velocities may exceed 50 m/s over large regions, the need for dealiasing is unavoidable. In the absence of data gaps along the Doppler radial (hereafter "ray"), a standard Bargen-Brown method using the in-situ wind at the aircraft as a first guess is generally effective at dealiasing the Doppler radial velocity. Greater challenges arise where data gaps along the ray coincide with large wind speed gradients. Dealiasing beyond a large gap is a challenge unless some reasonable first-guess wind speed is known across the gap. This scenario naturally occurs when the aircraft is within the hurricane eye and the first meteorological echo along the ray may be >10 km from the radar in a region of pronounced wind speed gradient. The current automated NOAA QC constructs low-azimuthal-wavenumber analyses using Doppler velocity data collected over an entire transect through the storm (inbound and outbound, but discarding ray observations beyond large gaps) to provide the needed first-guess wind speed across large gaps along a ray. The standard Bargen-Brown method may then be employed to dealias the Doppler velocity. While this method is mostly effective in real-time operations, it is time intensive in that it requires an initial low-wavenumber analysis be performed before the full three-dimensional analysis, and it does not permit dealiased rays to be transmitted off the aircraft until the low-wavenumber analysis is completed at the end of the storm transect.

The need to dealias Doppler velocity can be mitigated somewhat by employing a dual-PRF technique to extend the effective Nyquist range. As summarized by Alford et al. (2022):

> "In the dual-PRF method, two uniform timeseries are collected sequentially at different PRTs [Pulse Repetition Time] to produce a single ray of data. Velocities … derived from each time series are combined to obtain a new (dealiased) velocity estimate with a corresponding larger maximum unambiguous velocity."

Given a high PRF value, $PRF_h$ (2775 Hz) and low PRF value, $PRF_l$ (1850 Hz), that hold to the following ratio (e.g., Altube et al. 2017):

$$PRF_h / PRF_l = N+1/N, \text{ where N is an integer} > 1,$$

the extended Nyquist velocity is given by $V_{nyq,e} = N^*V_{nyq,h}$, where $V_{nyq,h}$ is the Nyquist velocity associated with $PRF_h$. For N=2, a 3:2 ratio of PRF values, the Nyquist range is doubled and less dealiasing, overall, is required. Operating in dual-PRF mode, however, comes at a cost. As summarized by Alford et al. (2022):

> "…increasing the Nyquist interval can enhance the potential for range ambiguities, which may overlap and contaminate first-trip signals (Zrnic and Mahapatra 1985)."

These dual-PRF processor errors are often clustered in high shear areas of the flow. Thus, simply removing them would be detrimental to resolution of the hurricane eyewall flow, for example. A method developed by Alford et al. (2022) identifies and attempts to correct (and not simply remove) these dual-PRF errors.

**Goal(s):** Develop a next-generation capability for automated velocity dealiasing that eliminates the need for a low-wavenumber analysis currently employed as part of real-time TDR processing, and permits near real-time streaming of quality-controlled Doppler radials.

**Objectives:**

1. Collect a dual-PRF TDR dataset from one or more transects through the eyewall and eye of a mature hurricane.
2. Demonstrate the reduced occurrence of aliased Doppler velocities in the hurricane eyewall compared to a that from a single-PRF transect of the storm.
3. Evaluate the efficacy of the Alford et al. (2022) dual-PRF processor error correction method in the hurricane context.

**MATURE STAGE EXPERIMENT**
***Science Description***

---

**Aircraft Pattern/Module Descriptions (see *Flight Pattern* document for more detailed information):** The P-3 flies a short pass (~25 n mi legs inbound and outbound) through the eyewall and eye while the TDR is in dual-PRF mode. Time permitting, repeat a short pass along a different azimuth for diversity of measurements.

**Links to Other Mature Stage Experiments/Modules:** *Ocean Winds, Surface Wind and Wave Validation*

**Analysis Strategy:** TDR (Sigmet) sweep data are converted to CfRadial format and processed by Alford et al.'s ProcessorCorrect python routine (github.com/aaddisonalford/processorCorrect). The sweep data, before and after correction, will be viewed using Solo3 to address the stated objectives.

1) Address Objective 2 by comparing sweeps from single-PRF passes (before/after the dual-PRF module) and dual-PRF passes. A *qualitative* assessment of the extended range of non-aliased Doppler velocity values and decrease in the relative number of aliased rays when using the dual-PRF technique is sufficient.
2) Address Objective 3 by quantifying the removal of dual-PRF errors through ray-by-ray comparisons of uncorrected and ProcessorCorrect-modified data.

**References:**
Alford, A. Addison, Michael I. Biggerstaff, Conrad L. Ziegler, David P. Jorgensen, and Gordon D. Carrie. "A Method for Correcting Staggered Pulse Repetition Time (PRT) and Dual Pulse Repetition Frequency (PRF) Processor Errors in Research Radar Datasets", *Journal of Atmospheric and Oceanic Technology* 39, 11 (2022): 1763-1780.
Altube, P., J. Bech, O. Argemí, T. Rigo, N. Pineda, S. Collis, and J. Helmus, 2017: Correction of Dual-PRF Doppler Velocity Outliers in the Presence of Aliasing. *J. Atmos. Oceanic Technol.*, 34, 1529–1543.
Zrnic, D. S., and P. Mahapatra, 1985: Two methods of ambiguity resolution in pulse Doppler weather radars. *IEEE Trans. Aerosp. Electron. Syst.*, AES-21, 470–483.