MATURE STAGE EXPERIMENT
Science Description

Experiment/Module: TDR Analysis Evaluation Module

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Requirements: Categories 2–5

Plain Language Description: Three-dimensional wind analyses derived from two P-3 aircraft equipped with tail-Doppler radar (TDR) and flying simultaneous, perpendicular transects through the hurricane eyewall are compared in an evaluation of the Doppler-radar wind analysis method. Through this evaluation, we seek to gain a better understanding of how to relate radar-derived peak wind speed and other aspects of hurricane wind structure to similar estimates using conventional observations.

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: Since 2019, TDR wind analyses have been available to NHC hurricane specialists in AWIPS-II, but there remains uncertainty as to how the product can be used to estimate quantities like peak surface wind speed and surface wind radii. Although prior work has demonstrated good agreement between conventional flight-level wind speed measurements and nearby analyzed radar wind speed estimates, no such evaluation exists for radar wind speed estimates well away from the flight track. Because the lag between fore and aft radar measurements (needed to retrieve the wind vector at a grid point) increases with range from the aircraft, and the increasing physical volume of the radar pulse with range, it is presently unknown how peak wind speed estimates at long range are quantitatively degraded from radar estimates made within the peak wind region. Furthermore, the general sensitivity of the 3-D TDR wind retrievals to flight track has not yet been documented outside of limited idealized studies. Some sensitivity is expected based *inter alia* on how the various wind components project onto the Doppler radials as the aircraft transects the hurricane eyewall region.

Background: Several studies have evaluated TDR wind analyses near the flight track (e.g., Marks et al. 1992; Gamache et al. 1995; Reasor et al. 2000; Morrow 2008; Reasor et al. 2009; Reasor and Eastin 2012). Generally, these studies have conducted comparisons using high-resolution flight-level wind data interpolated to TDR analysis grid points (following the 3-D interpolation method of raw Doppler radial data). In their along-track evaluation of TDR wind analyses in Hurricane Guillermo, Reasor et al. (2009) and Reasor and Eastin (2012) found mean errors in tangential wind < 1.5 m/s and rms errors of 3-4 m/s. The errors decreased significantly when only points within the eyewall region were considered. For the radial component, mean errors were an order of magnitude less and the rms errors were comparable. It should be remembered, however, that near standard flight levels, radial flow values are generally an order of magnitude less than tangential wind values. The correlation between flight-level and TDR-derived tangential wind (0.98-0.99) is much higher than that for radial wind (0.81-0.85). Vertical motion in the hurricane eyewall region is associated with highly localized convective processes and much weaker mesoscale ascent/descent associated with stratiform processes. Because the mass continuity constraint in the TDR wind retrieval involves divergence over a spatial scale much larger than actual convective updrafts/downdrafts, it is not quite appropriate to compare flight-level vertical motion and TDR-retrieved vertical motion on a point-by-point basis. Reasor et al. (2009) did show that, overall, frequency distributions for flight-level and TDR-derived vertical motion compared favorably.

In an evaluation of analysis quality throughout the domain, Lorsolo et al. (2013) used simulated Doppler radials (but without physical beam volumes or near-surface data removal) sampled from a nature-run snapshot of Hurricane Paloma (2008). They found that the tangential wind component was best retrieved, with a mean error < 0.5 m/s and rms error < 2 m/s. The radial wind retrieval errors were comparable, but the retrieval was somewhat less accurate. Vertical wind retrieval is the most challenging. Although the rms errors were smaller than those for radial and tangential wind, the rms errors normalized by the expect range of vertical motion values greatly exceeded similar estimates for the horizontal wind components throughout the lower to middle troposphere. Additional sources of error not considered by Lorsolo et al. include errors in hydrometeor fall speed removal and errors arising from the use of the mass continuity constraint under realistic conditions where the data quality control may remove much of the data below 1-km altitude. The TDR Analysis Evaluation Module seeks to collect datasets that will enable the most comprehensive 3-D evaluation of non-simulated radar-retrieved wind and reflectivity analyses of hurricanes to date.

Goal(s): Quantify the sensitivity of TDR-derived peak wind speed estimates to radar range and orientation of the radar beam relative to the horizontal wind vector. Quantify the general robustness of the 3-D TDR wind retrievals and standard derived diagnostics, and develop a greater understanding of the primary causes for coherent regions of large discrepancy. Verify pre-season reflectivity calibration corrections and assess impacts of attenuation on the representation of reflectivity structures within the eyewall and near-core vortex.

Hypotheses:

1. Due to TDR pulse-averaging over larger spatial scales and diminished temporal resolution through increased fore-aft scan lag, peak TDR-retrieved wind speed values at larger radar range will be reduced from corresponding *in-situ* estimates.
2. Enhanced sensitivity of the TDR wind analysis to eyewall transect orientation will arise where significant differences in orientation of the radar beam relative to the horizontal wind vector exist.
3. At the lowest levels of the TDR wind analysis, where large deviations of weighted mean position of data from a grid point *and* large vertical gradient of the flow exist, larger errors in the wind retrieval, especially in the radial component, will arise.

4. TDR-derived diagnostics which rely primarily on the rotational component of the flow will depend only weakly on eyewall transect orientation.

Objectives:

1. Collect simultaneous measurements of peak eyewall wind speed from two TDRs at different (order 30-km) radar range.
2. Collect independent, near-simultaneous (center crossings <5 min of each other) TDR velocity measurements along orthogonal flight tracks within the eyewall region.
3. Collect independent, near-simultaneous (center crossings <5 min of each other) TDR reflectivity measurements along orthogonal flight tracks within the eyewall region.

Aircraft Pattern/Module Descriptions (see *Flight Pattern* document for more detailed information): Two P-3 aircraft will fly P-3 Pattern #1, which entails simultaneous perpendicular transects through the eyewall region such that, as one P-3 nears the hurricane center, the other P-3 samples the inbound or outbound peak-wind region of the eyewall. The eyewall radius should not be so small that rapid crab angle changes contribute to substantial gaps in TDR eyewall coverage, and not so large that the eyewall is only marginally resolved within the TDR analysis swath (*maximum* distance from the flight track to the edge is 50 km). An optimal eyewall radius for this module is ~30 km. Furthermore, precipitation should be sufficiently symmetric to maximize TDR analysis coverage, especially within the eyewall.

Links to Other Mature Stage Experiments/Modules: Surface Wind and Wave Validation Module and NESDIS Ocean Winds Experiment

Analysis Strategy: TDR analyses with standard grid spacing (2-km horizontal and 0.5-km vertical) will be performed in near-real time and transmitted to NWS operational centers via AWIPS-II. A post-flight reprocessing of TDR data collected as part of the module will be performed for Level 2 research community access. Essential components of the simultaneous TDR analysis evaluation:

1) Compute statistics for point-by-point analysis comparisons.
2) Identify regions of coherent difference in analysis difference fields. Evaluate sources of significant difference by considering beam geometry, solution method, flow evolution, etc.
3) Identify maximum analyzed wind speed along flight track from “eyewall aircraft” and compare with simultaneous analyzed wind speed from “center aircraft”. Examine the TDR pulse volumes contributing to maximum analyzed wind speed from the respective aircraft.
4) Compare TDR analyses with flight-level data and other independent observations (e.g., dropsondes), as available.
5) Compute (minimally-attenuated) reflectivity histograms from the two P-3s to assess consistency of radar calibrations.

References:

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