

Title: NOAA P-3 Tail Mounted X-Band Doppler Radar Data (VORTEX-SE - 2018)

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1.0 Data Set Overview:

This document describes observational and data characteristics of the National Oceanic and Atmospheric Administration (NOAA) P-3 dual airborne tail Doppler radars (TDRs) that were operated in support of the Verification of the Origins of Rotation in Tornadoes EXperiment - SouthEast - 2018 (VORTEX-SE - 2018) project from 10 March to 15 April 2018. The NOAA P-3 was operated during VORTEX-SE - 2018 in collaboration with teams from the University of Oklahoma (OU)/Cooperative Institute for Mesoscale Meteorological Studies (CIMMS), the University of Alabama - Huntsville, the University of Louisiana - Monroe, the National Severe Storms Laboratory, and the NOAA Aircraft Operations Center (AOC). The P-3 aircraft was operated by the NOAA/AOC in collaboration with and via scientific mission guidance provided both prior to and onboard during each "intensive operation period" (IOP) by the NSSL Science Team led by P-3 Chief Scientist Conrad Ziegler.

2.0 Instrument Description:

The NOAA P-3 is equipped with state-of-art, AOC-fabricated, dual 360° vertically scanning solid-state X-band (wavelength 3.22 cm) Doppler radars (e.g., Ziegler et al. 2018; Jorgensen et al. 2017). The dual, flat-plate, slotted-waveguide antennas are mounted within a rotodome in the tail section that is driven by a custom, NCAR-fabricated motor and rotary joint. Although rotation rate is variable, the TDRs were operated at their maximum rotation rate of 20 RPM throughout VORTEX-SE - 2018. With the rotation axis parallel to the fuselage, and the two flat-plate antennas mounted on opposite sides of the rotation axis (antennas directed +/-20° in the forward/aft direction), each 360° sweep consists of a truncated, approximately conical (more precisely, flattened helical) section. At a nominal operating cruise speed of roughly $\sim 100 \text{ m s}^{-1}$, adjacent 360° sweeps are spaced roughly $\sim 300 \text{ m}$ apart in the along-track direction, yielding an effective along-track Nyquist wavelength of about 0.6 km. The effective minimum resolvable along-track wavelength assuming four (4) adjacent gate measurements is about 0.9 km. Much earlier versions of the P-3 TDR are described by Jorgensen et al. (1983), Ziegler et al. (2001), and Jorgensen et al. (2003).

For questions, comments, concerns, or more information, contact the NSSL P-3 Chief Scientist and VORTEX-SE -2018 NSF Co-Investigator: Conrad Ziegler (conrad.ziegler@noaa.gov).

3.0 Data Collection and Processing:

The NOAA P-3 dual TDRs each employ the SIGMET/Vaisala RVP-900 processor to configure and control scanning and radar sampling. Each data file contains the sweep file data for a specific TDR (forward or aft) in their native SIGMET (RVP-900) format for one mission day (IOP). Measured TDR variable fields (discussed further in sections 4.0 and 5.0 below) include reflectivity, radial velocity, spectrum width, and a signal quality index that provides a measure of signal coherency.

Since Doppler radars are subject to the well-known tradeoff between maximum unambiguous range and maximum unambiguous velocity, the P-3 TDRs employ a dual-pulse repetition frequency (i.e., "dual-PRF") scheme for mitigating velocity ambiguities and extending the Nyquist velocity co-interval (Jorgensen et al. 2000). Typical obtained operational values were a 48 km unambiguous range and a 49.9 m s^{-1} unambiguous velocity, the latter approaching up to roughly ~80% or more of typical bulk tropospheric shear magnitudes during most VORTEX-SE deployments. Due to the large Nyquist velocity, velocity aliasing (if any) was typically concentrated in the upper level divergent outflow around the downshear flank of targeted supercells. During VORTEX-SE, a PRF ratio of 3/2 was employed to obtain optimal results with very low processor error rates (Jorgensen et al. 2000). The locally developed Python radar editing script discussed later in this section includes a robust algorithm that automatically detects and corrects TDR dual-PRF processor mistakes.

These P-3 TDR datasets combine all periods of data collection on a given operational day. The TDRs are typically turned on (and data recording begun) early during the ferry flight from base to the initial IOP operating area, are continuously operated in close coordination with VORTEX-SE ground-based teams during the targeted IOP data collection, and are turned off during the return ferry to base after VORTEX-SE operations have been declared ended for the given IOP. The TDRs perform very robustly and have been distinguished by essentially continuous nominal operation during VORTEX-SE.

The time variable of TDR sweeps is Universal Time (UTC). Users should note the UTC time change through 0000 UTC for some VORTEX-SE missions that extended into the (usually early) night-time hours of the given calendar deployment day.

Careful data editing is required to conduct single- or dual-/multiple-Doppler radar analyses or assimilation into model ensembles using these TDR observations. Typical software tools used to edit TDR sweep files include the following:

- (1) RadxConvert - Radx library (convert sweeps from SIGMET to CFRADIAL, DORADE, etc);
- (2) Solo (peruse and perform various manual or semi-automated edits on DORADE sweeps);
- (3) Python script based on Py-ART to perform various automated edits.

The Radx and Solo libraries are available from NCAR/EOL. A locally developed Python radar editing script is currently undergoing continuous improvements (including several new features tailored specifically for NOAA P-3 TDRs), and its design/description has been submitted for formal journal review. Following the latter formal publication, it is planned to post the Python script to a public-accessible repository for dissemination.

Removing effects of aircraft motion and instantaneous 3-D orientation may be accomplished using Solo by either of two methods. Both correction methods are based on applying known aircraft orientation and motion via Solo to improve ray navigation and obtain ground-relative velocities that are each important for conducting radar analysis. The first method, which directly utilizes P-3 flight level measurements recorded in the SIGMET sweep files to effect navigation corrections and remove aircraft motion, has been demonstrated to be quite effective for the nominally straight, level P-3 flight legs used to obtain supercell observations during VORTEX-SE. A second method, in which a constrained CFAC navigation file is first derived and then input/applied in Solo, could potentially increase ray navigation accuracy in cases of turbulent *in situ* flight conditions or legs that deviate significantly from the typical straight/level mission profile performed during VORTEX-SE.

4.0 Data Format:

The processed/recorded TDR fields include the following:

DBZ_TOT ("Uncorrected" Reflectivity)
DBZ ("Corrected" Reflectivity)
VEL (Mean Radial Velocity)
WIDTH (Doppler Spectrum Width)
SQI (Signal Quality Index for Doppler coherency [0 to 1])

The SIGMET processor combines and compresses all ingested files from one sweep into a single file for each sweep, referred to as the raw product which composes this EOL-archived dataset. All of the raw products for a specific TDR/IOP are archived into a single tar.gz file.

For a more detailed description, every byte of every file produced is defined in the programmer's manual found at:

ftp://ftp.sigmet.vaisala.com/outgoing/manuals/IRIS_Programmers_Manual.pdf (Vaisala 2017a)

Some useful sections of "IRIS_Programmers_Manual.pdf" are the following:

- (1) 4.3.1 Extended_Header Format (DB_XHDR)
- (2) 4.3.4 2-byte Reflectivity Format (DB_DBT2& DB_DBZ2)
- (3) 4.3.27 2-byte Signal Quality Index Format (DB_SQI2)
- (4) 4.3.30 2-byte Velocity Format (DB_VEL2)
- (5) 4.3.36 2-byte Width Format (DB_WIDTH2)
- (6) 4.4 Ingest Data File Format
- (7) 4.5.4 RAW Product Format

The other IRIS manuals can help in describing the data/moments:

ftp://ftp.sigmet.vaisala.com/outgoing/manuals/IRIS_Radar_Manual.pdf (Vaisala 2017b)

ftp://ftp.sigmet.vaisala.com/outgoing/manuals/IRIS_Product_and_Display_Manuals.pdf (Vaisala 2017c)

5.0 Data Remarks:

Note on ground target contaminations: Ground target contaminations of sweep data from airborne radars must be detected and removed during preliminary editing (e.g., as described in section 3.0) to assist in generating quality reflectivity and radial velocity airflow syntheses or model assimilations. The most obvious manifestation of ground clutter is the quasi-horizontal band of high-reflectivity and near-zero ground-relative radial velocity centered around the terrain profile (i.e., roughly at the P-3's height AGL). Careful inspection of TDR sweeps from VORTEX-SE (2017-2018) also indicates the presence of substantial velocity contamination above the surface due to (low-reflectivity) sidelobe ground returns. Due to unknown sidelobe ray geometry, ground velocity sidelobe contamination cannot be "corrected" for aircraft motion and must instead be removed via TDR editing as discussed in section 3.0.

Note on clear air detection by the TDRs: Current, ongoing research by the author and collaborators suggests that the new TDRs may be sensitive to clear air motions given the presence of adequately high insect scatterer concentrations in the boundary layer (BL). However, the insect concentrations likely vary widely both with IOP and spatially/temporally during a given IOP. Additionally, insect concentrations may be weaker during these early-Spring, cool-season VORTEX-SE data collections than during the warm season over CONUS. Thus, these relatively weak BL echoes may likely be mixed with the aforementioned (weaker-echo) sidelobe ground target contaminations, requiring very careful editing to isolate (if possible) gates with coherent returns in a given TDR scan.

For more information please contact Conrad Ziegler.

6.0 Data Attribution:

When using these NOAA P-3 airborne tail Doppler radar data in presentations, informal publications, or formal publications, it is requested that the user(s) kindly include proper attribution to the data authors/providers: **"Conrad Ziegler of the National Severe Storms Laboratory (NSSL) is acknowledged for his efforts in obtaining flight hour support for the NOAA P-3 service during VORTEX-SE (2018), with additional thanks to the NOAA P-3 flight crew and NSSL science team for acquiring the VORTEX-SE dataset. The P-3 data collection effort also received support from the NSSL Director's Discretionary Research Fund."**

7.0 References:

Jorgensen, D. P., P. H. Hildebrand, and C. L. Frush, 1983: Feasibility test of an airborne pulse-Doppler meteorological radar. *J. Clim. Appl. Meteor.*, 22, 744-757.

Jorgensen, D. P., T. R. Shepherd, and A. S. Goldstein, 2000: A dual-pulse repetition frequency scheme for mitigating velocity ambiguities of the NOAA P-3 airborne Doppler radar. *J. Atmos. Ocean. Tech.*, 17, 585-594.

Jorgensen, D. P., Z. Pu, P. Ola G. Persson, and W.-K. Tao, 2003: Variations associated with cores and gaps of a Pacific narrow cold frontal rainband. *Mon. Wea. Rev.*, 131, 2705-2729.

- Jorgensen, D. P., C. L. Ziegler, E. N. Rasmussen, A. A. Alford, and A. S. Goldstein, 2017: Improvements to the NOAA P-3 airborne Doppler tail-mounted radar: Supercell observations from VORTEX-Southeast. 38th Conf. on Radar Meteor., Chicago, IL.
- Vaisala, 2017a: Programming guide - IRIS. Helsinki, Finland, 145 pp.
- Vaisala, 2017b: User guide - IRIS radar. Helsinki, Finland, 115 pp.
- Vaisala, 2017c: User guide - IRIS product and display. Helsinki, Finland, 403 pp.
- Ziegler, C. L., E. N. Rasmussen, T. R. Shepherd, A. I. Watson, and J. M. Straka, 2001: The evolution of low-level rotation in the 29 May 1994 Newcastle-Graham, Texas, storm complex during VORTEX. *Mon. Wea. Rev.*, 129, 1339-1368.
- Ziegler, C. L., T. A. Murphy, K. L. Elmore, M. I. Biggerstaff, Z. Wang, E. N. Rasmussen, D. P. Jorgensen, and A. A. Alford, 2018: Kinematics, thermodynamics, and microphysics of the tornadic 13-14 April 2018 Calhoun, LA supercell during VORTEX-SE. 29th Conf. on Severe Local Storms, Stowe, VT.