Title: NOAA P-3 Tail Mounted X-Band Doppler Radar Data (TORUS - 2022)

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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 Targeted Observations using Radars and UAS in Supercells (TORUS-2019) project from 17 May to 15 June 2022. The NOAA P-3 (NOAA42) was operated during TORUS-2022 in collaboration with teams from the University of Oklahoma (OU)/ Cooperative Institute for Severe and High-Impact Weather Research and Operations (CIWRO), the University of Nebraska, the University of Colorado, the University of Michigan, the Texas Tech University, 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 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 TORUS-2022. 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 ~ 110 m s^{-1}, adjacent 360° sweeps are spaced roughly ~ 330 m apart in the along-track direction, yielding an effective along-track Nyquist wavelength of about 0.66 km. The effective minimum resolvable along-track wavelength assuming four (4) adjacent gate measurements is about 1 km. Much earlier versions of the P-3 TDRs 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 TORUS 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 (i.e., "intensive operation period" or 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 54 km unambiguous range and a 44.4 m s^{-1} unambiguous velocity, the latter approaching up to roughly ~80% or more of typical bulk tropospheric shear magnitudes during most TORUS 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 TORUS, 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 TORUS ground-based teams during the targeted IOP data collection, and are turned off during the return ferry to base after TORUS operations have been declared ended for the given IOP. The TDRs perform very robustly and have been distinguished by essentially continuous nominal operation during TORUS.

The time variable of TDR sweeps is Universal Time (UTC). Users should note the UTC time change through 0000 UTC for some TORUS 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 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 (Alford et al. 2022).
The Radx and Solo libraries are available from NCAR/EOL. A locally developed Python script for editing airborne and ground-based radar data includes several new features tailored specifically for NOAA P-3 TDRs, and a formal manuscript reporting its design, description, and testing has been accepted for publication (Alford et al. 2022). 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 TORUS. 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 TORUS.

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. 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., at a distance below roughly the P-3's flight level altitude (AGL). Careful inspection of TDR sweeps from TORUS-2022, TORUS-2019, and 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. 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.

Note on TDR performance during TORUS-2022: As pointed out in section 3.0 above, the TDRs have been distinguished by essentially continuous nominal operation during TORUS. However, cabin overheating during flight #6 (IOP7) caused the TDR processor computers to shut down between leg #9 and leg #11 on storm #1 (2139 - 2154 UTC).

For more information please contact Conrad Ziegler.

6.0 References:

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